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APPLICATION OF PASSIVE SAMPLERS FOR MONITORING O_3 AND NO_2 AND CORRELATION OF CONCENTRATION LEVELS WITH METEOROLOGICAL DATA

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Abstract

This research applied passive air pollution samplers to monitor the concentration of the pollutants nitrogen dioxide (NO_2) and ozone (O_3) in order to investigate the relationships between pollutant concentrations and meteorological variables. The study was carried out in three strategic sites in the municipality of Erechim, Brazil, which provide intense traffic of small and large vehicles. The pollutant analyses were performed using the method of UV/VIS spectrophotometry. NO_2 concentrations varied between values below the detection limit of the passive samplers and 5.2 µg m^{-3}, whereas the concentrations of O_3 ranged from values below the detection limit of the passive samplers to 23.6 µg m^{-3}. These values are within the O_3 and NO_2 concentration ranges currently allowed by Brazilian law. Low values of correlation coefficients were observed between the meteorological variables and the concentration for both pollutants and the three sampling points. However, it was verified more evident trends for precipitation and wind speed. As the emission sources were found to be highly variable, O_3 studies have to be held for longer periods in order to allow the proposition of the most appropriate forms of emission control.

Keywords: atmospheric pollution, nitrogen dioxide, ozone, passive monitoring, passive samplers

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1. Introduction

Air pollution is a problem that has been greatly aggravated since the 19th century due to factors such as industrialization and the circulation of automobiles. Santana et al. (2017) state that automobile traffic is one of the main causes of air pollution, which is drastically intensified by traffic jams, a major problem in Brazilian cities. Thus, effective mitigation and control of air pollution require an understanding of the trends and changes in vehicular emissions (Banica et al., 2017; Lang et al., 2012).

Ozone (O_3) and nitrogen dioxide (NO_2) are pollutants commonly found in large urban and industrial centers. Whenever these gases are above certain levels, the concentration of such pollutants in Earth's atmosphere can severely harm human health (Malik and Tauler, 2015) by causing chronic and acute respiratory and cardiovascular diseases (Curtis et al., 2006; Hosseinibalam et al., 2010; Latza et al., 2009; Lee et al., 1996, 2014; Mavroidis and Ilia, 2012).

NO_2 is a pollutant that comes from both natural sources and anthropic activity related to the burning of fossil fuels, such as coal, gas, and oil power plants (Felix and Elliott, 2014; Galloway et al., 2004). The concentration of NO_2 in the atmosphere is closely related to automobile traffic. Long-term exposure to this gas may impair the immune system and lead to respiratory infections (Adon et al., 2016; Chauhan et al., 1998; Delgado-Saborit and Esteve-Cano, 2006; Dunea et al., 2014; Kampa and Castanas, 2008). The impact of prolonged exposure to air pollution on

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human health can only be quantified by means of regular and continuous monitoring of pollutant concentration (Lin et al., 2016). Therefore, it is increasingly necessary to find ways to quantify pollutant concentrations in urban areas.

Ozone is a secondary pollutant that is formed in the troposphere by photochemical reactions between nitrogen oxides (NOx) and Volatile Organic Compounds (VOCs) (Tiwari et al., 2015). Castell et al. (2010) explained that it is necessary to control the formation of tropospheric ozone in the environment in order to reduce and prevent the harmful effects on both human health and the environment (Tang and Lau, 2000). Other authors explained that the oxidative process caused by the activity of ozone in the cell wall and membrane in plants generates a mechanism of oxidative stress that results in the production of a reactive oxygen species and free radicals, which are harmful to both human health and the environment (Drapikowska et al., 2016; Pennell and Lamb, 1997; Rao et al., 2000).

Besides being important due to its relation to health problems, monitoring these pollutants in the environment is essential to establish control measures and identify their sources. In this context, methods based on active or passive air quality samplers constitute the mainstream ways of quantifying the concentration of pollutants in the atmosphere. The passive sampling method is widely used since it does not require a power supply for operation, once its operation utilizes the natural molecular diffusion to capture the gases by means of absorber solutions, in most cases. Passive samplers are low-cost and can be done without an electrical power supply. Further, their application requires little training (Seethapathy et al., 2008). Thus, it can be extensively used in multiple locations in order to provide information on the spatial distribution of air pollution concentration (Hangartner, 2000).

In general, passive sampling is interesting for monitoring air quality for several advantages, including low cost, simplicity of the method, easy to operate; does not require any power source, calibration, or maintenance; all parts of the samplers are reusable; passive samplers offer flexibility as they can be fixed to poles, traffic tunnels, parks, building, etc.. Passive samplers remain stable for several months after sampling, can be conveniently transported before and after exposure, and are ideal for the development of large spatial monitoring work, even in remote areas with no power source or elaborate infrastructure (Namiesnik et al., 2005; Varshney and Singh, 2003).

However, limitations and sources of errors in passive sampling are related to the determination of the diffusion velocity and depend on the sampler geometry and the diffusion coefficient, which, being specific for each pollutant, varies with atmospheric pressure and temperature. If the geometry of the sampling device is not optimal, the thickness of the stagnant air layer near the collection surface may change with turbulence and wind intensity, which influences the rate of pollutant transfer (Harrison and Perry, 1986). Other issues involve the inability to provide real-time concentration information, which limits the assessment of short-term fluctuations (Varshney and Singh, 2003).

Over the last decade, it has been a common practice to apply and validate passive samplers in different places of the world in order to evaluate the concentration of different pollutants types in the Earth's atmosphere. As examples, one can cite Spain (Lozano et al., 2009), USA (Smith et al., 2015), China (Li et al., 2015), Italy (Venturi et al., 2016), Brazil (Tominaga et al., 2016; Santana et al., 2017, 2019), Tibet (Wang et al., 2016), Turkey (Özden and Döğeroğlu, 2008, 2012; Özden Üzmez et al., 2015) and the United Kingdom (García et al., 2017). However, few studies have been devoted to evaluating the effects of meteorological factors on the results of the measurements made by passive samplers. One of the few studies is the one by Masey et al. (2017), which evaluated three types of passive samplers and compared the variations in the results to wind speed, thus finding that the variation of the positive absorption rates is linearly associated with wind speed for two types of samplers. Santana et al. (2019), applying multivariate analyzes to passive measurements of formaldehyde and acetaldehyde in the atmosphere, also evaluated correlations between concentration levels of the measured aldehydes and meteorological parameters, such as temperature and precipitation.

This paper presents unpublished data on measured concentrations of two main atmospheric pollutants in a medium-sized city in Brazil and attempts to establish a relationship between pollutant concentrations and the main meteorological factors that are important as explanatory variables.

2. Material and methods

2.1. Sampling

The study was carried out in three strategic sites in Erechim, a medium-sized city with approximately 100,000 inhabitants that is located in the Northern region of the Rio Grande do Sul state, Brazil, where there is intense traffic circulation, including both small- and large-size vehicles. The locations and geographical coordinates of the passive samplers were: (P1) Industrial District (27°38'55.10"S; 52°14'41.92"O); (P2) BR-153 Highway (27°38'54.29"S; 52°15'11.76"O); and (P3) Downtown (27°37'59.84"S; 52°16'28.13"O) (Fig. 1).

Two passive samplings were placed in each site, one for each of the gaseous pollutants being considered. These were placed in a traffic light at 2 m height with no shelter and with the diffusing wall facing downwards. The samplers were exposed on the second Friday of each month and remained in the location for 5 days. The sampling period was from June 2015 to July 2017. After the exposure period, the samples were removed and sent to a laboratory for

analysis, where they were wrapped in aluminum foil to isolate and store the samples and then stored under refrigeration until the analysis was performed, following the procedures indicated in Campos et al. (2006).

A sampler for each pollutant was exposed at the P1 site under the same conditions as the others but this sampler was completely sealed in plastic film (polyvinyl chloride – PVC), in order to simulate a blank to use as a reference.

2.2. Sampler configuration

The two pollutants studied used the same sampler model (Fig. 2) which was based on the model described by Campos et al. (2006). The sampler consisted of a cylindrical polyethylene tube with 12mm height and 21mm diameter sealed at the bottom, a gas inlet with a diffusion wall consisting of a Teflon membrane (Millipore, PTFE, 0.5 µm pore, 25 mm diameter, hydrophobic and smooth), and a stainless steel screen (0.08 mm x 0.125 mm) to prevent the ingress of particulate matter into the sampler and provide protection to the filters with the absorber solution.

The sampling methodologies were based on the work of Campos et al. (2010) for NO_2 and Bucco (2010) for O_3. The methodology of Bucco (2010) was selected for O_3 monitoring because it also uses the UV/VIS spectrophotometry method, unlike other methods that involve the use of ion chromatography, for example. What differentiates the sampling for each pollutant is the type of absorber filter, the solutions used to absorb the compound at the exposure site (Table 1), and the analytical quantification methodology described in section 2.3.

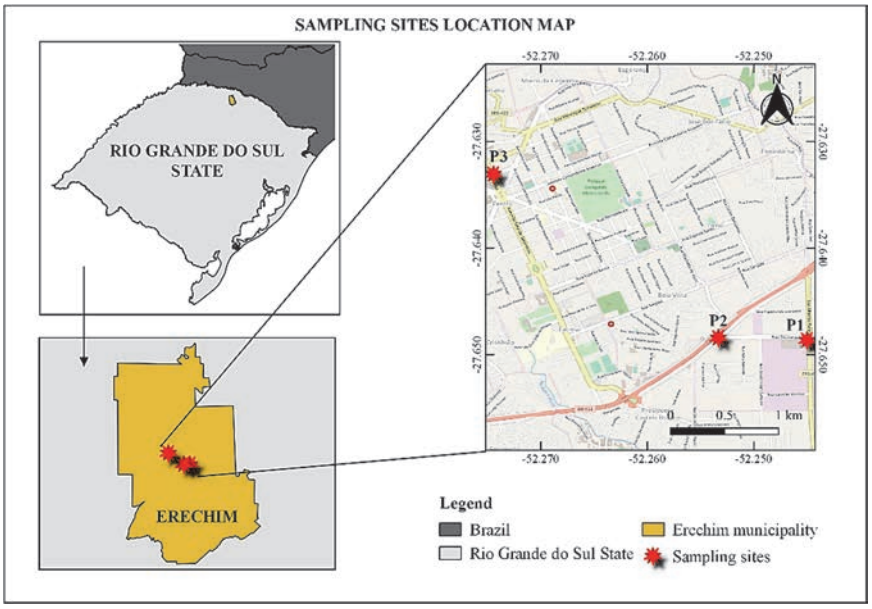

Fig. 1. Sampling sites location map: P1 – Industrial District; P2 – BR-153 Highway; P3 – Downtown

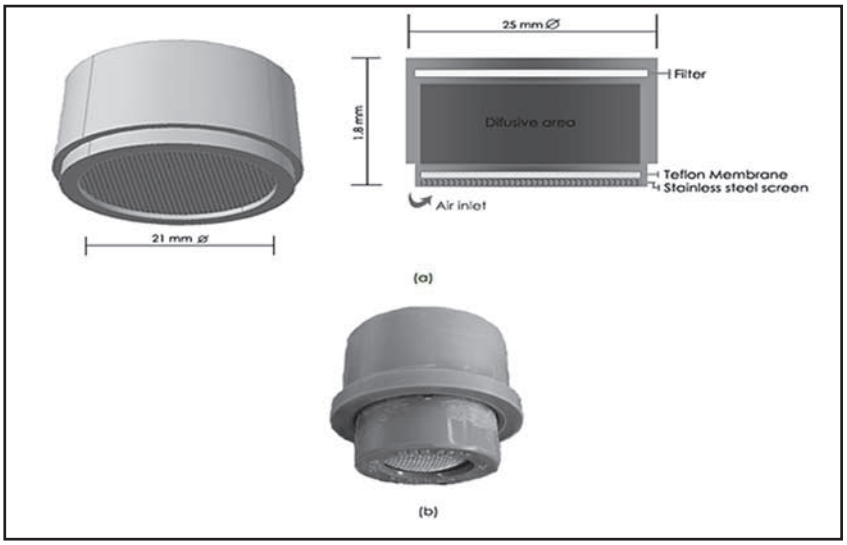

Fig. 2. Passive sampler used for monitoring pollutants: (a) Dimensions and layout of the sampler; (b) Real photo of the sampler (Daris et al., 2016)

2. 3. Analytic methodology

Pollutant analysis was performed using UV/VIS spectrophotometry methods. In order to quantify the O_3, the method recommended by Bucco (2010) was used, whereas for NO_2 the modified Griess-Saltzman method (Saltzman, 1954) as used by Campos et al. (2010). Both methods use UV/VIS spectrophotometry. Thus, it was necessary to construct calibration curves from standard solutions of known concentrations for each compound.

The pollutant concentration was determined following the principle of Fick's first law of diffusion, according to (Eq. 1) (Palmes and Lindenboom, 1979):

$$C = (m \cdot L)/ (D \cdot A \cdot t) \quad (1)$$

where C is outdoor (environment) concentration of gas (μg m^{-3}); m *is* the total collected mass (μg); L the length of the line of diffusion (m); D is the coefficient of diffusion (m^2 h^{-1}) obtained from the literature; 0.3769 m^2 h^{-1} according to Massman (1998) for NO_2 and 0.3999 m^2 h^{-1} for O_3; A is the cross-sectional area of the line of diffusion (m^2), and t is the sampling time (h). The total collected mass *(m)* can be obtained from (Eq. 2):

$$m = C_{abs} \cdot V \quad (2)$$

where C_{abs} is the result obtained from the absorbance values converted to a concentration value (mg L^{-1}) applying the calibration curve; and V is the quantity of reagent solution used to extract the compounds absorbed by the filters, which are 0.005 L for NO_2 and 0.025 L for O_3.

2.4. Meteorological data

The meteorological data refers to accumulated precipitation, wind speed, relative humidity, total radiation, and average temperature that were collected for five days for each month during the period from June 2015 to July 2017. This information was then compared to the variation of pollutants concentration. For this work, the values of these parameters were obtained from the National Institute of Meteorology (INMET) (BRASIL, 2016) website, from the Erechim weather station (Station Erechim – A828).

3. Results and discussion

3.1. NO_2 pollutant

Fig. 3 illustrates the ambient concentration of the NO_2 pollutant during the period between June 2015 and July 2017. The graph shows the highest value among the three sites considered in the study, which are identified by the labels P1 (Industrial District), P2 (BR-153 highway), and P3 (Downtown). All monitored values were below the primary standards (annual average concentration of 100 μg m^{-3}) established by CONAMA 003/90 Resolution (BRASIL, 1990), which is the closest legal standard to passive sampling.

The passive sampler exposed in P1 completely sealed to be used as reference (blank) resulted in an average concentration of 0.15 ± 0.10 μg m^{-3} for the entire sampling period, which may be the result of field or analytical interferences. Thus, it is possible to determine a detection limit in which concentrations below this value have a higher level of associated uncertainties. The detection limit was calculated from the mean of the blank samples plus three times the observed standard deviation and resulted in 0.46 μg m^{-3}. This value was similar to the detection limit obtained by Campos et al. (2010) for a period of exposure of the one-week samplers (0.21 μg m^{-3}).

Table 1. Specifications of filters and absorber solution for each pollutant

Pollutant	*Filter*	*Absorbing solution*	*Reference*
NO_2	Cellulose filter (Whatman 40)	KI 5.0 × 10^{-1} mol L^{-1} + KOH 2.0 × 10^{-1} mol L^{-1} in methyl alcohol. Volume used for impregnation in the filters: 0.2 mL.	Campos et al., (2010)
O_3	Fiberglass filter (GF 50/A)	Make a paste of 5.0 g of starch in 20 mL distilled water and place it in 50 mL boiling distilled water for five minutes. Put the solution aside for 24 hours and dissolve 1.0 g of potassium carbonate followed by 10.0 g of potassium iodate and dilute it for 100 mL. Volume used for impregnation in the filters: 1 mL.	Bucco, (2010)

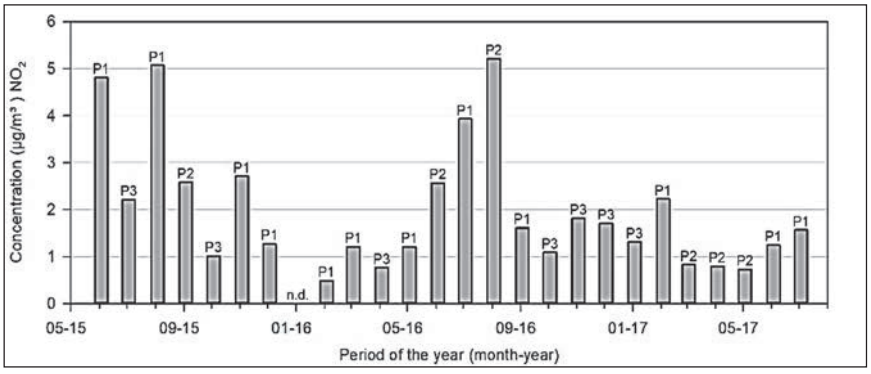

Fig. 3. Maximum concentrations of NO_2 for each month from June 2015 to July 2017.
Sample labels are P1: Industrial District; P2: BR-153 Highway; P3: Downtown. (n.d.: not detected)

The months of August 2015 (5.1 µg m^{-3} in P1) and August 2016 (5.2 µg m^{-3} in P2) presented the highest concentration values for the three sites considered. One of the hypotheses for this behavior is the fact that this is a period of the beginning of the school semester, resuming the vacation period. Another hypothesis may be related to the flow of trade being greater, due to the economic flow of the city. Alternately, January 2016 (< 0.46 µg m^{-3} for all points) and February 2017 (0.7 µg m^{-3} in P2) presented the lowest concentrations, thereby showing that the concentration for the pollutant NO_2 was negligible during the five days of sampling. The value below the detection limit for the month of January 2016 may be related to the vacation period since the month of February of the same year also presented a low value for this pollutant.

Similar values of NO_2 concentrations were also obtained in other studies with passive samplers for medium-sized cities, such as that of Daris et al. (2016), which obtained values in the same magnitude range, smaller than 8 µg m^{-3}, for a city of a similar size with about 200,000 inhabitants (Passo Fundo); and Marc et al. (2016), which obtained average values of 17 to 25 µg m^{-3} to Tczew and Sopot, respectively, cities in Poland with fewer than 100,000 inhabitants.

Meanwhile, Bucco (2010) evaluated concentrations for a big Brazilian city, Curitiba, and determined greater concentrations, with a maximum value of 80 µg m^{-3}. Adon et al. (2016) also evaluated two African cities-Dakar and Bamako, each of which have a population of millions of inhabitants and obtained the average values of 83.2 µg m^{-3} and 31.0 µg m^{-3}, respectively. This brief comparison allows the inference that the evaluated concentrations are within the ranges observed in the literature in medium-sized cities and below those observed in large cities.

Campos et al. (2010), who proposed the methodology used in this study for NO_2 sampling, performed the validation of their results of the passive sampling from the comparison with continuous and calibrated reference methods. The authors did not observe significant differences between the results obtained by both methods ($p < 0.0001$ and $R = 0.9556$). Moreover, for different exposure periods (7 to 28 days), the accuracy (expressed as a percentage relative to error) of the measurements with the passive samplers varied between 2.0 and 12%, with an average of 6.8%.

Other authors have also studied the development of passive samplers for NO_2 monitoring utilizing methodologies similar to those used in the present study. Souza et al. (2017) developed low-cost samplers with conical centrifuge tubes. This methodology is based on the absorption of NO_2 in a cellulose filter impregnated with triethanolamine. After sampling, the analyte is solubilized and placed to react with the Griess-Saltzman solution. The authors obtained a correlation coefficient $R = 0.979$ between the concentrations obtained through passive samplers and commercial NOx samplers. Thus, it was concluded that, even with the use of low-cost materials, it was possible to develop a passive sampler and validate their conditions of use.

Campos et al. (2006) carried out the monitoring of urban areas of Salvador and nearby areas using the same methodology presented in this study with a two-week exposure time. The accuracy of the passive samplers, defined as the relative standard deviation for the exposed samplers, was determined at each point in the sampling network: 2.1 to 9.8% in the concentration range of 2.3 to 11 µg m^{-3} for NO_2, values considered compatible with citations in the literature on the accuracy of measurements with this type of sampler. In this sense, such studies demonstrate a good efficiency of this kind of sampler, which is considered adequate for the monitoring of NO_2 and for studies that do not require continuous or instantaneous sampling, since the results are given in concentration averages for certain periods of exposure.

3.2. O_3 pollutant

Fig. 4 illustrates the concentration results obtained for O_3 during the period from June 2015 to July 2017. The graph shows the highest value observed in each month among the three studied sites, according to the identification label. All monitored values are below the primary standards (mean concentration for 1 hour of 160 µg m^{-3} which should not be exercised more than once per year) established by CONAMA 003/90 Resolution (BRASIL, 1990), which is the closest legal standard to evaluate the concentrations obtained by the passive sampling technique in Brazil. The isolated passive sampler used as a blank resulted in an average concentration of 3.14 ± 0.83 µg m^{-3}, which may be the consequence of field or analytical interferences. Then, the detection limit calculated from the mean of the blank samples plus three times the observed standard deviation was 5.65 µg m^{-3}.

The concentrations of O_3 ranged from values below the detection limit in four months (< 5.65 µg m^{-3}) to 23.6 µg m^{-3} (May 2016 at P2). Concentrations below the detection limit for the period from June to August may be related to the climatic conditions involved during the winter months, not favoring the formation of this pollutant, such as lower values of radiation associated with other factors that involve the entire process generation of O_3 in the troposphere. The site with the highest concentration of NO_2 was not the same as O_3, even though it could be a secondary pollutant from NO_2. According to Delmas et al. (2005), the highest concentrations of O_3 are not necessarily close to their precursor's emission source and may focus on remote areas.

Similar values were also found by Daris et al. (2016), who obtained a maximum value of 20.81 µg m^{-3} in Passo Fundo, Brazil, a medium-sized city. Other studies that also used passive samplers obtained similar concentrations, such as in Dakar and Bamako (Adon et al., 2016), two large African cities with mean

values of 24.5 μg m^{-3} and 4.8 μg m^{-3} respectively; and for Curitiba (Bucco, 2010), with a maximum observed value of 30 μg m^{-3}. This comparison shows that the values of O_3 are not related to the size of the city, nor are the values of NO_2; and it also supports the hypothesis that O_3 may be concentrated in remote areas, due to the dispersion of its primary inductive pollutants and its formation away from the emission focus.

3.3. Study of the correlation between pollutant concentration levels and meteorological parameters

Fig. 5 and Fig. 6 shows the results of the linear regression between the concentration of NO_2 and O_3 for each point and the meteorological parameters in the exposure periods of passive samplers. The scarce existence of correlation studies between meteorological data and the concentration of the pollutants is due to several factors, such as the nature of the pollutants, which means the pollutant itself is not sensitive to the changes caused in the atmosphere by meteorological parameters. Another factor is related to the distance from the sampling site to the site of the measurement of meteorological data since the concentration of the pollutant is measured locally and the concentration difference over great distances can be quite large.

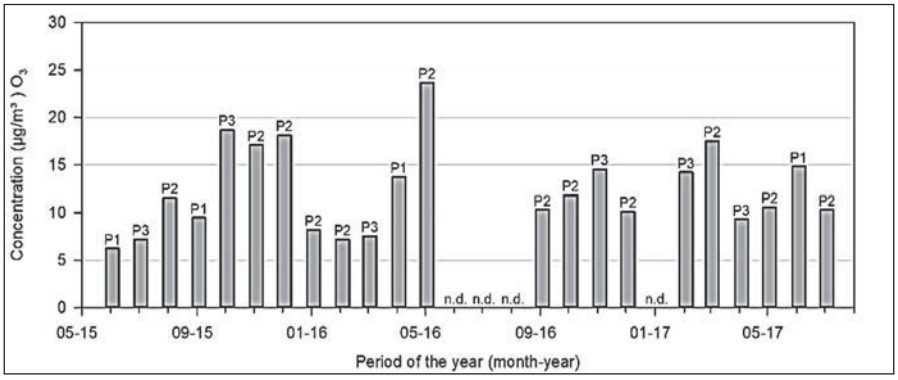

Fig. 4. Maximum O_3 concentrations of each month from June 2015 to July 2017. Labels are P1: Industrial District; P2: BR-153 Highway; P3: Downtown. (n.d.: not detected)

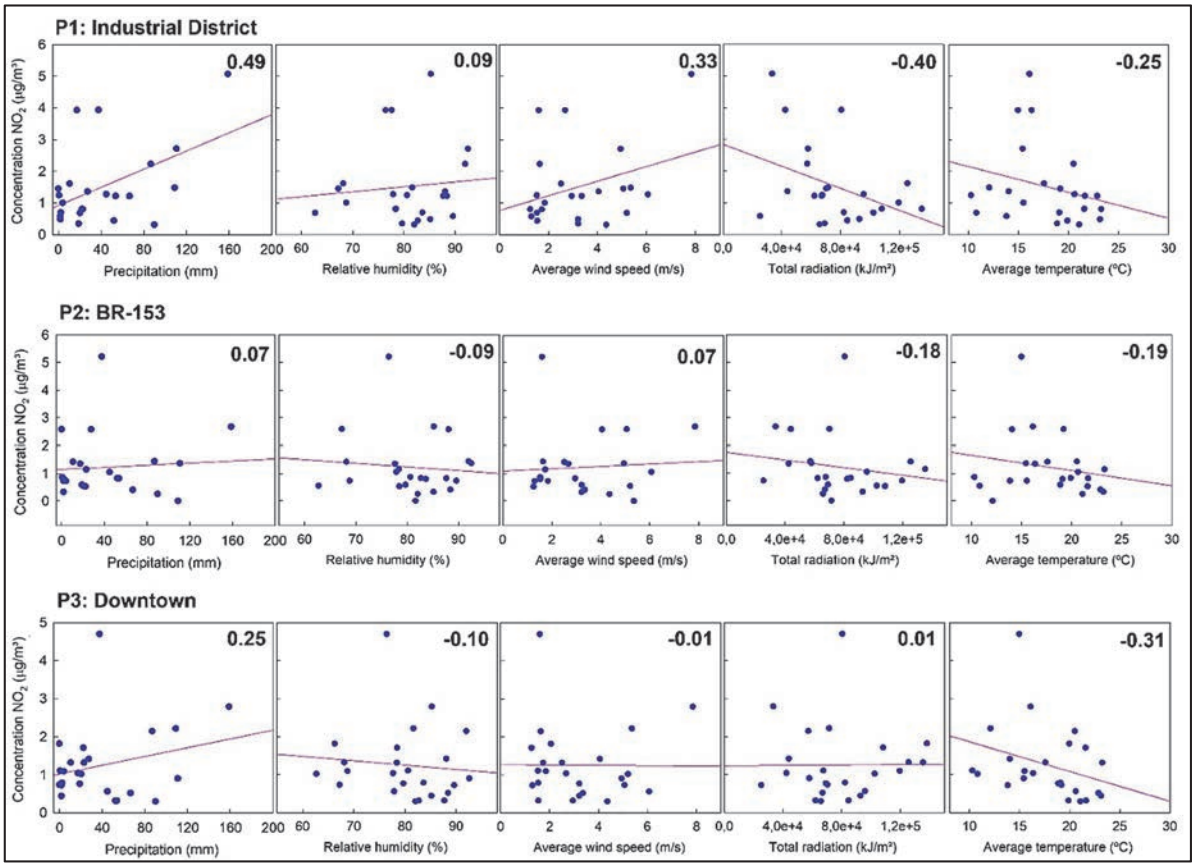

Fig. 5. Linear regression of the NO_2 and concentration for the three sampling sites in relation to the meteorological parameters surveyed. The value in bold represents the Pearson correlation coefficient (ρ)

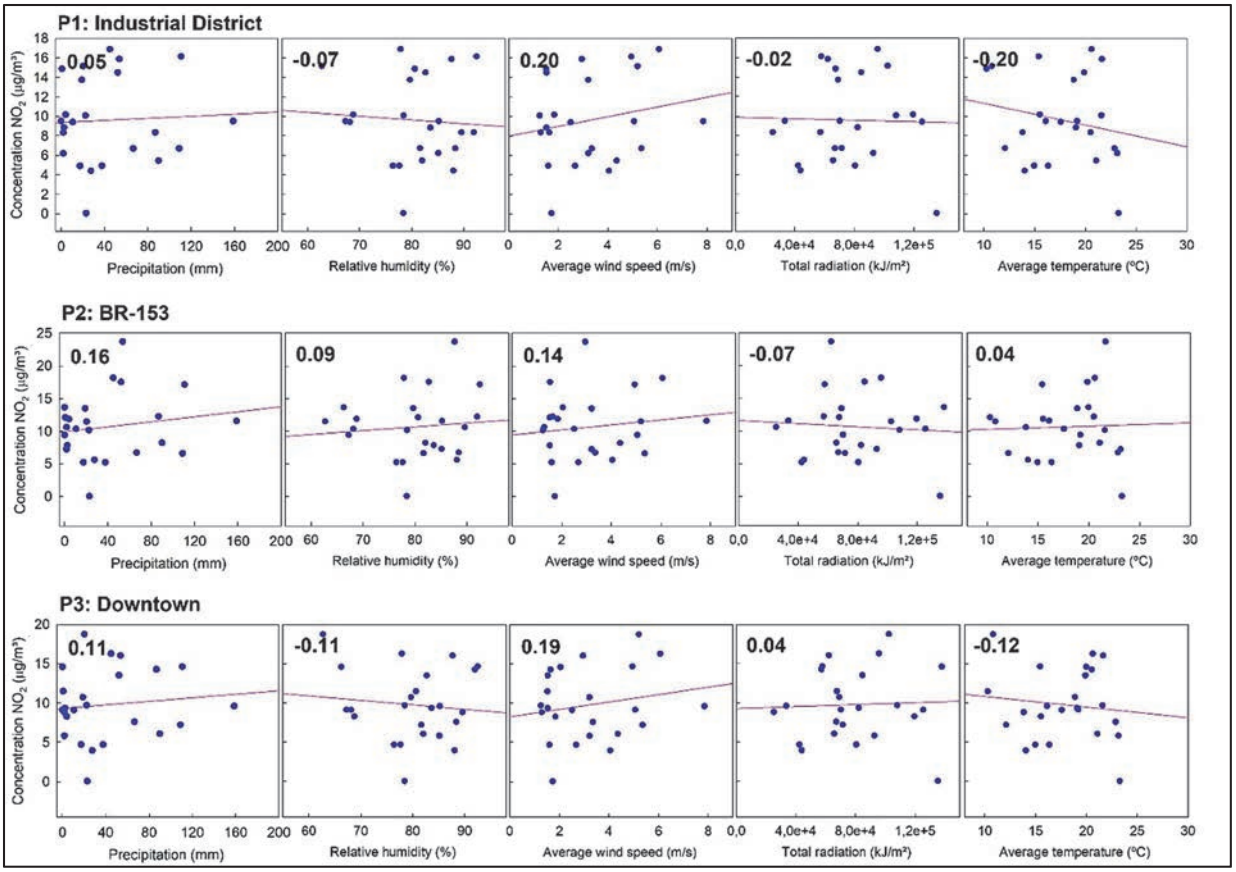

Fig. 6. Linear regression of the O_3 and concentration for the three sampling sites in relation to the meteorological parameters surveyed. The value in bold represents the Pearson correlation coefficient (ρ)

Although some parameters showed stronger correlations at some points than others with respect to concentrations of NO_2 and O_3, the positive or negative trend of influence is the same for each of the sampling points (Fig. 5 and Fig. 6). Besides that, despite low values of correlation coefficients, clearer and more evident trends are observed, such as for precipitation and wind speed. For both pollutants and for the three points, precipitation shows a positive trend with respect to the concentrations of the compounds. Precipitation events are capable of promoting the washing effect, which is responsible for helping to remove pollutants from the atmosphere under certain conditions, that depends on some parameters, such as rates of emission of pollutants, the growth rate of raindrops, and the rate of raindrops falling on the ground (Kim et al., 2014; Shukla et al., 2008). As an example, Shukla et al. (2008) verified that gaseous pollutants are easily removed from the atmosphere when the rates of conversion of these pollutants into particulate matter and rainfall are large. On the other hand, studies have shown that precipitation can lead to adverse effects. For example, according to Kwak et al. (2017), precipitation events may result in an increase of the concentrations of compounds; this may be due to an increase in traffic volume, and the slowing down of vehicles as an additional result of increased traffic. Taking into account that sampling sites have a heavy daily traffic flow, traffic conditions are expected to be strongly altered as a result of adverse weather conditions. Therefore, an increase in concentrations of certain pollutants can be observed in precipitation events, resulting in a positive correlation between concentration values and rainfall volume. Another study also observed increased O_3 concentrations during precipitation events (Yoo et al., 2014). The authors stated that this phenomenon can also be a result of vertical mixing associated with the convection leading to the downward O_3 transport from the lower stratosphere/upper troposphere.

Fig. 7 shows the behavior of the mean concentrations of NO_2 and O_3 with the cumulative volumes of precipitation. It can be verified that in months with high rainfall volumes, high concentrations of both pollutants were observed, whereas in months in which no precipitation events occurred showed the concentrations remained low. Therefore, a more in-depth assessment of the characteristics of precipitation events (intensity, frequency, etc.) and the traffic situations under such conditions should be carried out in order to obtain a better understanding of the phenomenon and its influence on the transportation dynamics in the region of study.

Fig. 8 shows the variation of the NO_2 (Fig. 8a) and O_3 (Fig. 8b) average concentrations in the three evaluated sites, compared to the average wind speed data during the sampled period. The linear regression results show a positive trend for the mean wind speed variable (Fig. 5). Also, a correlation evaluation

between precipitation and wind speed data collected during the study period resulted in a moderate relation (ρ = + 0.60), which indicates that higher wind speeds are related to precipitation events. For example, in August 2015, when the largest precipitation event was observed, the highest average wind speed was also observed, as well as one of the highest average concentrations of NO_2 (3.5 µg m^{-3}) (Fig. 8a). In August 2016, a low volume of precipitation and low wind speed also favored the occurrence of a higher-than-average concentration of NO_2 (4.61 µg m^{-3}) (Fig. 8a). Thus, the behavior of observed concentrations can be justified from the inferences previously made regarding the relationship between NO_2 concentrations and precipitation.

However, the same inferences are not applicable to the O_3 behavior, possibly due to the different dynamics involved in the formation of this secondary pollutant (Fig. 8b). Thus, as tropospheric ozone is formed from other primary pollutants (NOx, VOCs) and depends on other factors, such as radiation, for its formation, its direct relationship with wind speed and precipitation, as discussed for NO_2, cannot be evidenced.

Fig. 9 shows the variation of the average NO_2 (Fig. 9a) and O_3 (Fig. 9b) concentrations in the three evaluated sites, compared to the total radiation data during the sampled period. It can be observed that for some periods with higher values of total radiation, especially during summer (December to March), NO_2 concentrations remained relatively smaller (around 1 µg m^{-3}). This behavior can be justified by the increase in the rate of chemical reactions due to the greater intensity of solar radiation, which promotes the formation of secondary compounds such as NO, O_3, and other pollutants. For example, O_3 is generated *in situ* from the sunlight-initiated photochemistry oxidation of VOCs and in the presence of NOx (Jenkin and Clemitshaw, 2000; Jenkin et al., 2017; Mellouki et al., 2015). This corroborates the negative correlation obtained from the linear regression (Fig. 5). However, this effect is not observed for the case of O_3 (Fig. 8b and Fig. 6), which may be due to the fact that the analysis period is not able to cover the entire O_3 formation period, or because the formation is given for the area of analysis in the function of the advection and dispersion of the pollutants. Also, monitoring is not continuous and only represents the average of monitored days. Furthermore, O_3 formation may not be directly related to the presence of solar radiation alone; this process also depends on concentrations of other types of pollutants, such as VOCs, which were not monitored.

In the same way, the effect of temperature is directly related to the total radiation, presenting similar behavior (Fig. 10) and a negative correlation with the pollutant concentrations (Fig. 5). In addition, higher temperatures promote an increase in the rate of chemical reactions of the transformation of primary pollutants, as in the case of NO_2, for secondary pollutants (Cazacu et al., 2011; Gorai et al., 2015; Ynoue et al., 2006). Fig. 11 shows the variation of the average NO_2 (Fig. 11a) and O_3 (Fig. 11b) concentrations in the three evaluated sites and their relationship with relative humidity data compiled during the sampling period.

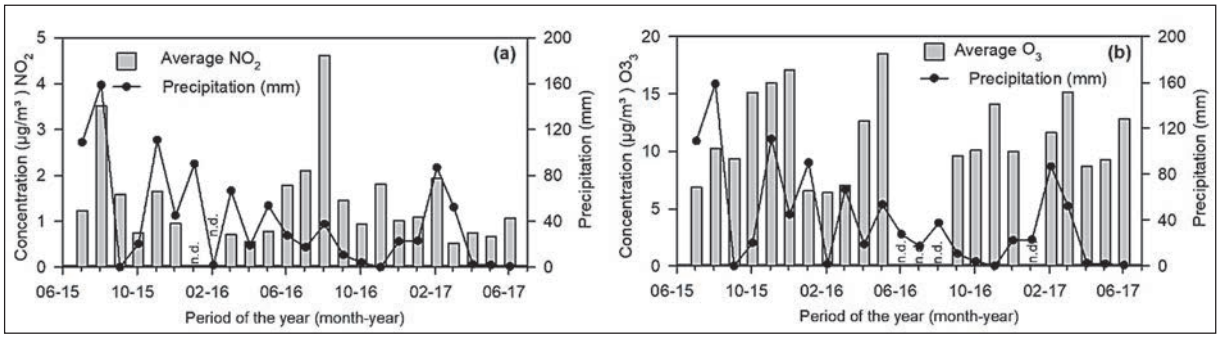

Fig. 7. Mean concentrations of the 3 sampling sites for (a) NO_2 and (b) O_3 compared to precipitation volumes. (n.d.: not detected)

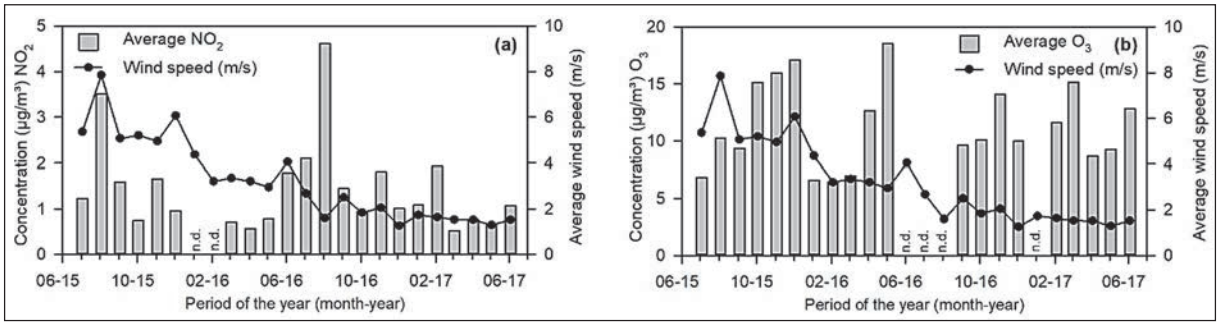

Fig. 8. Mean concentrations of the 3 sampling sites for (a) NO_2 and (b) O_3, compared to the average wind speed (n.d.: not detected)

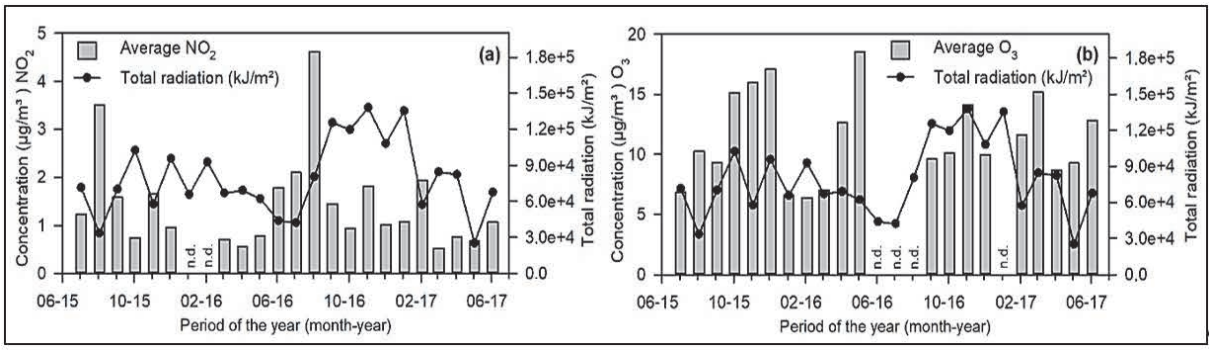

Fig. 9. Mean concentrations of the 3 sampling sites for (a) NO_2 and (b) O_3, compared to total radiation (n.d.: not detected)

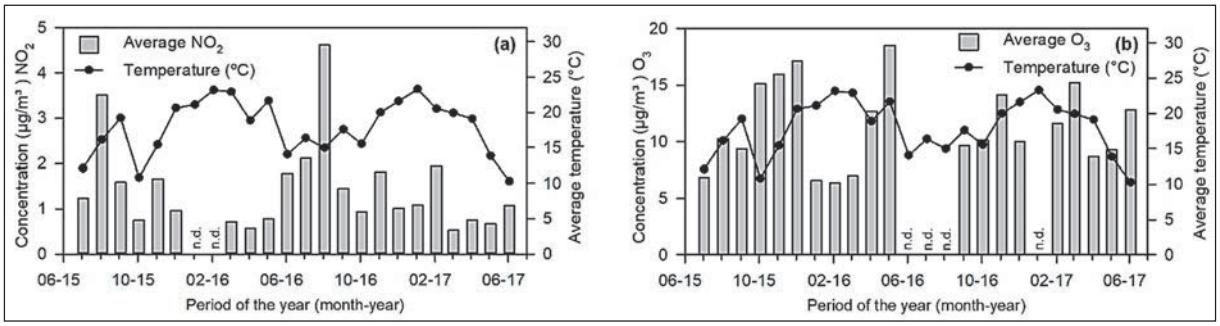

Fig. 10. Mean concentrations of the 3 sampling sites for (a) NO_2 and (b) O_3, compared to the average temperature (in °C) (n.d.: not detected)

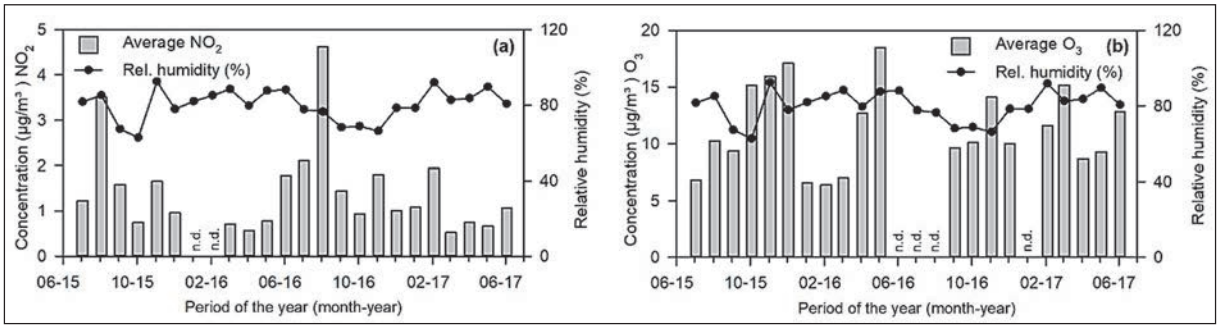

Fig. 11. Mean concentrations of the 3 sampling sites for (a) NO_2 and (b) O_3, compared to the average humidity (in %) (n.d.: not detected)

Additionally, Fig. 5 shows a tendency toward decreasing concentrations of both pollutants with the increase of relative humidity; this behavior is corroborated by other studies (Li et al., 2014; Radaideh, 2017). However, this relationship is not very clear when observing the behavior of O_3 concentrations, a fact also reported by Radaideh (2017). A study by Ocak and Turalioglu (2008) found that ozone concentrations are not only influenced by daily meteorological parameters, but also by pollutant concentrations from previous days. Ozone concentration increased with increasing wind speed, temperature, relative humidity, and O_3 concentration from previous days.

4. Conclusions

This work aimed to study the use of passive samplers to measure outdoor concentrations of NO_2 and O_3 pollutants and compare the findings with meteorological data. It was observed that passive samplers constitute an alternative procedure of air monitoring that can be easily applied in cities, with adaptive structural and low-cost analytical methods. In terms of representation and applicability, consistent results were observed and comparable to specific meteorological events during the monitored period.

The concentration values for the city of Erechim, Brazil, were below the O_3 levels allowed by the current legislation, which establishes a mean concentration for 1 hour of 160 µg m^{-3} that should not be exercised more than once per year, and NO_2, which establishes an annual average concentration of 100 µg m^{-3}.

However, this evidence should be evaluated with discretion, since passive sampling results is monitored and non-instantaneous average values that may exceed the values of the legislation during some periods of the day.

Regarding the influence of meteorological

factors, it was observed that the meteorological parameters that resulted in higher correlation coefficients were precipitation, average temperature for NO_2, and average wind velocity and precipitation for O_3, although there was a weak correlation for all parameters.

Since the emission sources are mostly variable and are primarily produced from vehicular sources, it is important to sustain related studies for a longer period in order to evaluate the most appropriate forms of emission controls, as well as to subsidize information for studies with pollutants others than those monitored. In addition, meteorological monitoring is important so that in a historical series of data, it is possible to assess causes and consequences with greater accuracy.

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