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Evaluation of Weather Conditions as Well as NO2 and PM 2.5 Levels in the Urban Areas of South Brazil in Different Seasons

Szczepaniak RF[1], Bainy B[1], Soares F[1], Moresco M[2], Fleck A[2], Rodhen C[2], Gamaro GD[1]

[1]Programa de Pós Graduação em Bioquímica e Bioprospecção (PPGBBIO), Universidade Federal de Pelotas, Campus Capão do Leão S/N Prédio 29 sala 303 Caixa Postal 354, CEP: 96010900, Pelotas/RS, Brazil
[2]Laboratório de Estresse Oxidativo e Poluição Atmosférica, Universidade Federal de Ciências e Saúde de Porto Alegre, Rua Sarmento Leite,245, Porto Alegre, RS, Brazil

[*]**Corresponding author:** Gamaro GD, Programa de Pós Graduação em Bioquímica e Bioprospecção (PPGBBio)/UFPel - Universidade Federal de Pelotas, Campus Capão do Leão S/N Caixa Postal 354, CEP 96010900, Pelotas, RS, Brazil. Tel: +55 (53)32757355, Email: giovanagamaro@hotmail.com

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Abstract

Due to the ever-increasing importance of studying pollution effects on environment and population, the development of methodologies for the evaluation of atmospheric pollutants has allowed great advances concerning air quality monitoring. Nitrogen dioxide (NO_2) and fine particulate matters (PM2.5) have as major sources vehicle engine exhausts and industrial processes. In the municipality of Pelotas, the economical and industrial growth allied to the expansion of the local vehicle fleet have brought several impacts on human health and environment. For this region, there are few studies concerning air pollution monitoring and dispersion. Data were collected seasonally (summer, autumn, winter and spring) in eight points (Porto, Areal, Centro, Fragata, Simões Lopes, Três Vendas, Laranjal,and Capão do Leão) over the city area, aiming to have a picture of the city as a whole. Annual mean ± standard deviation of the PM2.5 measurements are: Porto 48.95±6.28, Areal 3.29±4.56, Centro 39.56±7.05, Fragata 30.28±3.59,Simões Lopes9.5±.9, Três Vendas 3.4±3.80, Laranjal 29.79±2.34, Capão do Leão 24.25±3.2 and annual mean ±standard deviation for NO2 were: Porto 9.06±.5, Areal 0.49±0.94, Centro 4.3±0.89, Fragata 2.44±0.56, Trem 7.20±0.99, Três Vendas 2.94±.22, Laranjal 8.83±.97, Capão do Leão 6.77±0.76. We conclude that there are significantdifferences in different places of the city, mainly due to traffic and human activities characteristics of each point. On the other hand, meteorological factors act similarly in all sites concerning the pollution dispersion.

Keywords: Air pollution, Fine particulate matter, Meteorological parameters, Nitrogen dioxide, Exposure assessment, Seasons

Introduction

Atmospheric pollution is a global public health problem that causes millions of premature deaths per year worldwide. Moreover, atmospheric pollution is a factor that has been affecting humans and the environment [13,20].

Air quality has been a major cause of concern nowadays regarding the increasing concentration of pollutants in the atmosphere, which for many reasons exceed the established maximum standards. In urban areas, the main concern is related to the emission of pollutants by vehicle exhaust. Size and chemical composition are two of the main parameters that affect the way in which such pollutants correlate with population health. Ambient air pollution has been associated with a wide variety of effects on human health such as increased mortality risk, increased ratesof hospital admissions and emergency department visits, exacerbation of chronic respiratory conditions (e.g.,asthma), and decreased lung function. However, recently epidemiological data suggest a significant effect also of meteorological factors such as humidity, temperature, rainfall, and atmospheric pressure in interaction with pollutionlevels [15, 18, 5]. Particulate matter with aerodynamic diameter greater than 0 µm, or coarse particulate (PM0) have been contributing to the incidence and severity of respiratory diseases, mainly in urban areas. PM0 can penetrate into human lungs. Particulate matter with aerodynamic diameter smaller than 2.5 µm, or fine particulate ($PM_{2.5}$) may contain a high proportion of varioustoxic metals and organic compounds, among others. The increasing level of $PM_{2.5}$ has been shown to reduce pulmonary function and exasperate respiratory problems in respiratory compromised people, such as asthmatics [3, 11,17,].

Nitrogen dioxide (NO_2) is an air pollutant usually used as an indicator for air pollution generated by mobile and stationary sources. Gaseous nitrogen oxides are not exclusively radioactive or chemically active compounds, butthey may exhibit hazardous toxins, which in high concentrations represent a direct dangerous for human health [5, 10, 12]. Berger et al. (2006) [2] found that increased risk of supraventricular tachycardia in men with coronary heart disease was associated with NO_2, and Dockery et al. (2005) [7] found similar responses associated with the exposure to NO_2. Indeed, human exposure to high concentrationsof NO_2 reduces the immunity and resistance to respiratory tract infections (a high risk of catarrh of the upper respiratory tract, bronchitis, and pneumonia) [3, 12]. Thus, theincreasing evidence indicating that fine particulate matter in the atmosphere is responsible for adverse effects on humans led to the imposition of regulative restrictions on the emission of $PM_{2.5}$ as well as on NO_2.

There are several studies about the influence of meteorological systems on pollution dispersion from synopticto micro and local scales, which include aspects of terrain features. Since pollutants are released in the lowest part of troposphere, named Atmospheric Boundary Layer (ABL), the characteristics and behaviour of this layer may determine the air pollution concentration even more than the emission rate itself. On clear sky conditions under an anticyclone regime, for instance, there is a well-characterized evolution of ABL, which starts as a turbulence with sunrise and develops until the afternoon. During this process, the ABL height may reach several hundreds of meters,and this factor combined with vertical air motions are extremely favorable to pollution dispersion. Moreover, the stronger horizontal wind helps the dispersion to occur. On the other hand, during clear night, sky turbulence is suppressed and the ABL height may falls to few tens of meters. Under these conditions, thermal inversion is likelyto occur, confining pollution within the lowest meters above ground. Under a different condition, such as the action of a cyclone or convective system, mechanical turbulences generated by strong horizontal winds and rain are responsible for reducing the air pollution concentration through the processes of dispersion and wet deposition. Regarding topographical effects, the main features are the breezes (valley-mountain and sea/lake -land) due to their differential horizontal heating in microscale creating vertical circulation cells, which reach a few kilometers [19]. Gehrig and Buchmann (2003) [9], while discussing the seasonal and spatial distribution of particulate matter over Switzerland, stated that the huge seasonal variation on the pollutant concentration is much more related to meteorological effects (seasonality) than to any possible emission fluctuations, corroborating the important topographical influence on the pollution dispersion. Zhao et al. (2009) [22] found out that in the urban area of Beijing,the highest concentrations of $PM_{2.5}$ are observed in the winter and the lowest in the summer due to heat sources and lower ABL height during cold periods. They have also corroborated that in the summer and spring there are the most favorable conditions to dispersion: increased ABL height, stronger winds, and abundant precipitation.

The evaluated city, Pelotas, is located in the southernmost state of Brazil on a coastal plain and its urban area is situated at low altitude, with an average of 7 meters above the mean sea level. Pelotas is the third most populous city in the southern state of Rio Grande do Sul. It is located 250 Km away from Porto Alegre, the capital city of the state and 30 km from the Uruguay border. The Patos Lagoon lies to the East and the São Gonçalo Channel lies to the South, separating Pelotas from the city of Rio Grande (60 Km southeastwards). The city also hosts a significant agroindustrial park, important canneries, which have a production of more than 40 million cans of peaches a year, and the largest installed capacity of cattle slaughtering statewide. Pelotas is also the largest benefactor of rice inLatin America and has a significant fleet of vehicles that has increased 29.9% over the past five years according to the National Traffic Department in 20.

The climate of Pelotas is subtropical wet with warm and cold seasons. The two main meteorological systems responsible for rainfall are the extratropical cyclones (all over the year) and the convective systems (mainly in warmmonths). It is worth noting that, for the city, there are seasonal variations in human behavior and activities. In the winter, for instance, there is a large use of vegetal coal in house heating, and in the summer, there is a sharp increase in the population due to the proximity to the southern part of the Patos Lagoon, where the Laranjal B*each* is located.Considering all the above-mentioned reasons, in this study, we aimed at monitoring NO2 and PM2.5 of atmospheric pollution in all seasons of one year in the city of Pelotas.

Methods

Points of Environmental Monitoring

The eight points were chosen in order to represent the distribution of pollutants in the city as a whole (Fig. 1)

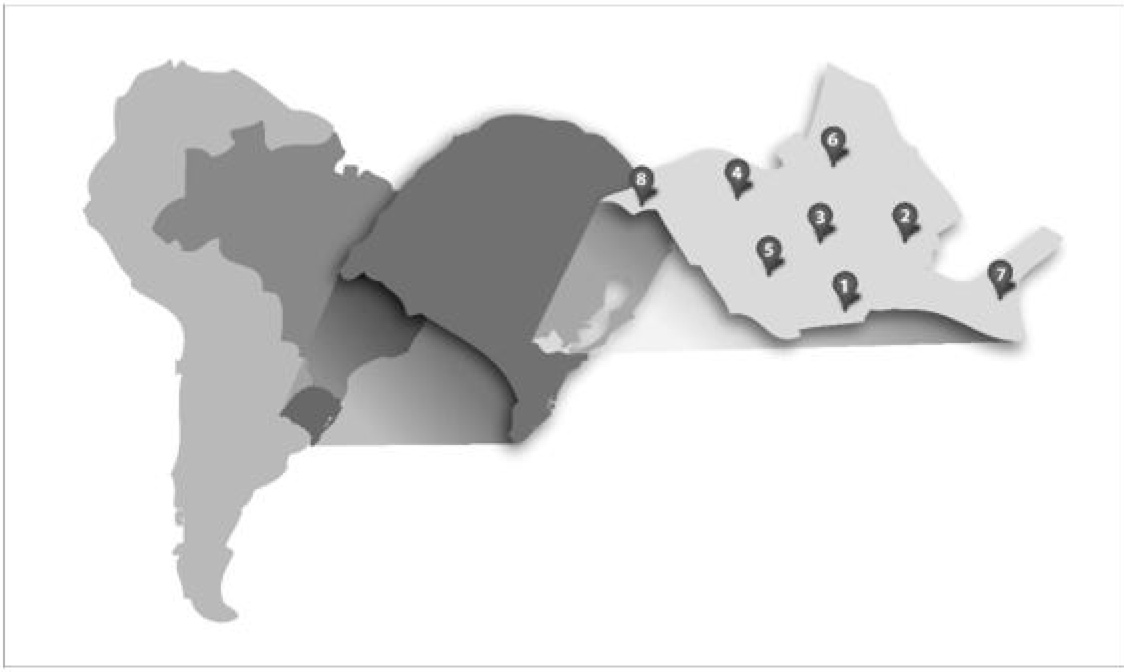

Figure 1: Sampling area locations in Pelotas the chosen sites are briefly described in Table 1

Site		Characteristic
1.	Porto 3°46’53” S 52°20’04” W	Fluvial harbor, poorly populated.
2.	Areal 3°45’” S 52°8’44” W	Urban area, highly populated. Way to the Patos Lagoon.
3.	Centro 3°25’48” S 52°20’30” W	Downtown -high traffic rate.
4.	Fragata 3°45’42” S 52°2’37” W	Urban area, highly populated.
5.	Simões Lopes 3°46’02” S 52°2’0” W	Close to downtown and to a train line.
6.	Três Vendas 3°44’0” S 52°20’40” W	Urban area, highly populated. Main entrance to the town.
7.	Laranjal 3°45’39” S 52°4’53” W	A *beach* at the Patos Lagoon. Area poorly populated in all the seasons but in the summer.
8.	Capão do Leão 3°45’46” S 52°25’08” W	Poorly populated, but close to a highway. Near the biggest University Campus, where meteorological data were collected.

Table 1: The monitoring sites and their respective characteristics

Measurement of Particulate Matter 2.5 Micrometer (PM2.5)

For the measurement of particulate matter (PM), we used the DustTrak equipment, Model 8520, TSIIncorporated, St. Paul, MN, USA. This equipment is designed to separate the particulate matter suspended in the air as inhalable (with maximum aerodynamic diameter smaller than 0 μm) or thin (with maximum aerodynamic diameter less than 2.5 μm) measuring the concentration of particulates on a filter bed, which has an infrared laser. Inthe case of this experiment, we monitored the portion of fine particulate material corresponding to MP2.5 for 48 h in all seasons (unless for some exception, for which the monitoring time ranged from 24-48h).

Monitoring Nitrogen Dioxide (NO2)

The sampling of NO2 is based on the principle of diffusion of atmospheric NO2 on filters in pulp impregnated with an absorbing solution for reaction with the gas [16]. The exposure of the filters was performed by means of plastic tube attached to trees in a stand of wood at a height of 2 meters at the monitoring points for 7 consecutive days in all seasons. In each monitoring point, a support containing six filters for sampling and another white filter were provided. The white filter consists of a filter sample not exposed to the atmosphere, whichremained in a clear plastic bag and sealed. After the extraction process, the samples were analyzed by photocolorimetry, and the samples were read in a spectrophotometer (Lambda 35 UV / VIS - Perkin Elmer ®) at 550 nm.

Statistical Analysis

Data were expressed as mean ± standard error. To assess the statistical difference between the concentrations of MP at different points, we applied the test of analysis of variance followed by Tukey post-hoc test, the significance level was set at 5% ($P \leq 0.05$). Data analysis was performed using SPSS version .0 (SPSS Inc., an IBM Company Headquarters, Chicago, IL, USA).

Meteorological Data

Meteorological data were provided by the Department of Meteorology from the Federal University of Pelotas(UFPel), for every ten-minute interval. For wind speed and direction, the hourly means were computed. Forprecipitation data, the hourly totals were computed.

Results and Discussions

The Brazilian National Ambient Air Quality Standard (NAAQS) sets the 24-h limit for coarse inhalable particulate matter (PM2.5-0) at 50 μg\ m^3. Nevertheless, for fine particles (PM2.5) there is no NAAQS [4].

In 2006, the annual mean PM0 concentration was 20 μg m^3 and was therefore (assuming again that PM2.5 accounts for 60% of PM0) estimated to be 0 μg\ m^3 annual mean and 24-h mean 25 μg\ m^3 for PM2.5 [21].

The results of PM2.5 in the eight points in all seasons of the year are presented in Table 2

Seasons	Summer		Autumn		Winter		Spring	
Points	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Porto	27.93	.30	69.62	9.2	84.59	3.92	3.66	0.8
Areal	25.97	.7	25.0	3.8	63.80	.7	0.29	.05
Centro	.9	0.76	42.60	3.7	78.66	8.07	25.09	6.2
Fragata	6.20	.63	52.58	3.68	4.06	8.26	.28	0.82
Simões Lopes	.82	.09	7.68	.35	36.47	4.94	0.63	0.28
Três Vendas	4.44	.78	40.97	3.44	40.77	7.48	29.42	2.53
Laranjal	8.9	0.35	7.95	.03	88.0	7.22	4.22	0.79
Capão do Leão	5.42	.38	8.68	2.82	37.69	6.6	25.2	2.48

Table 2: Concentrations of PM2.5 in the eight points of all the seasons (μg.m^{-3}). Data were expressed by mean ± standard errors

The analyses of PM2.5 (μg/m^3) during the summer sampling showed that the hugest concentration occurred in the points Porto (27.9±.3), possibly due to the storage of rice production and Areal (25.9 ± ,7), which provides access to the Patos Lagoon, where a great part of population spend time in the summer. Those points statistically distinguished from the others (ANOVA followed by Tuckey $P<0.05$). The points Centro (.9±0.76), Simões Lopes (.82±.09) and Laranjal (8.9±0.35) presented the smallest concentrations of PM2.5. According to Miranda (2002) [1,14], the great metropolitan area of Porto Alegre (about 250 km northwards from Pelotas) has more than 4 million inhabitants and 0.6 million vehicles and the average concentration of PM2.5 was 3.9 μm.m^{-3} in 2008, under the maximum established by World Health Organization (WHO). Porto Alegre is the major urban area of Rio Grande doSul. Its climate is strongly influenced by cold air masses migrating from the polar region, the seasons are clearly defined and the rain is well distributed throughout the year [6].

Figure 2 shows the time evolution for rainfall, wind speed and concentration of PM2.5. It is noticeable that for almostall the monitored point (excepting for the Laranjal *Beach*) there was an excess of fine particulate matter, at least in one hour. One interesting fact is that for the days 23 and 24, despite the significant rainfall (which is likely to favour wet deposition),there were reports of high concentrations of the pollutant. The concentrations also tend to respond the wind speed with a little delay. For example, a little time after the wind speed increases, there is a trend in reducing the PM2.5 concentration. According to the synoptic analysis, the most favorable days to high concentration of pollution would have been between days 26 and 3 due to favorable conditions to atmospheric stability, suppressing convection and air mixing, excepting days 27 and 28, when the rain should have carried away some of the total pollution. It is worth remembering that during summer time the ABL is more developed, that is, it has its top higher than in a cold period, which means that there is more volume of air available todilute the pollution.

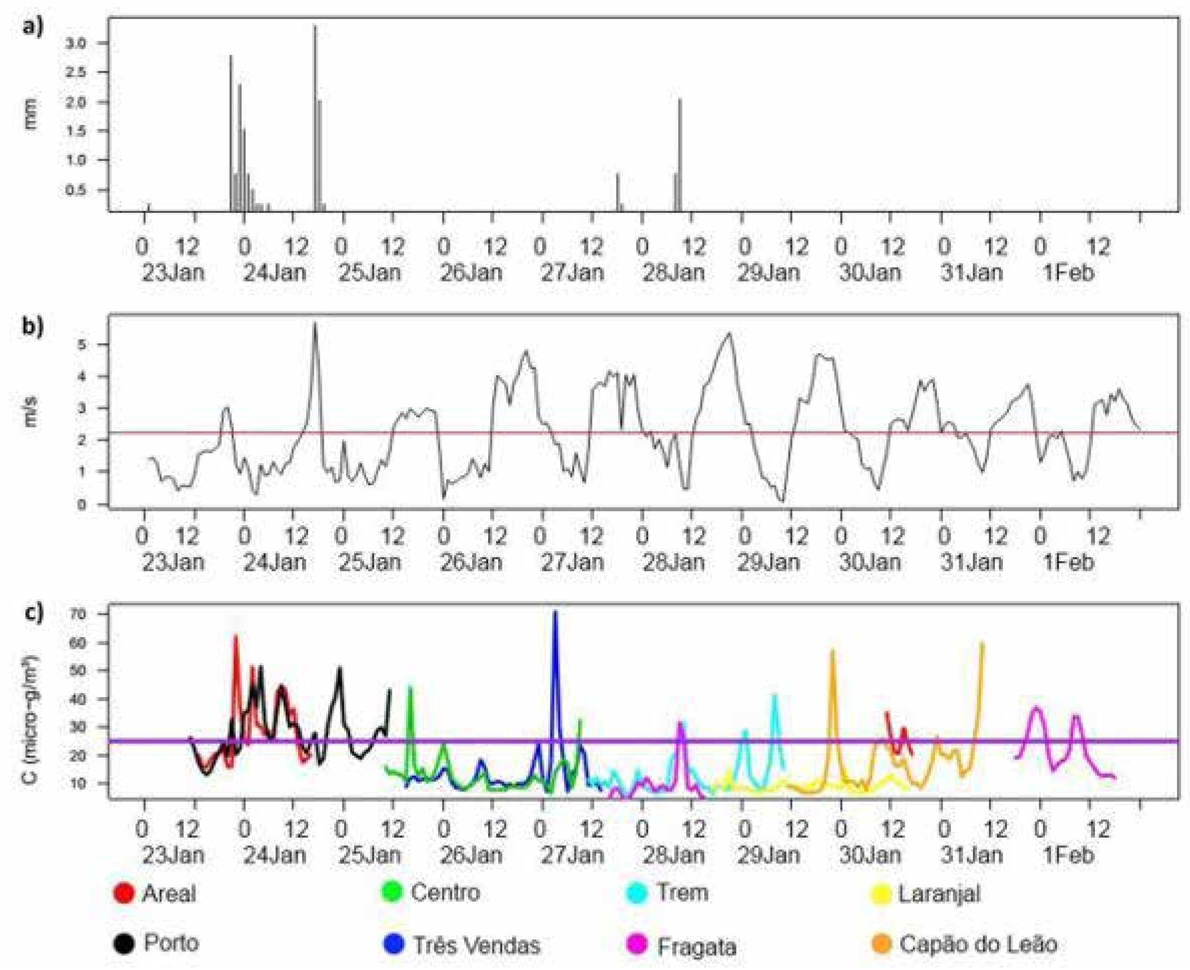

Figure 2: Time evolution for rainfall, wind speed and concentration of PM2.5 in summer of all points studied.
a) Time evolution for hourly rainfall, **b)** Hourly averaged wind speed (red line for total average) and **c)** Hourly averaged PM2.5 concentration for the monitored points (purple horizontal line for 25 μm.m^{-3}), for the summersampling. Hours expressed in Universal Time Coordinate (UTC -Greenwich Meridian Time), Local time = UTC - 2(summer) and UTC - 3 for the remaining seasons

The highest PM2.5 averaged concentration registers in autumn were in the points Porto (69.6 ± 9.) and Fragata (52.5± 3.6). The latter has a very important avenue that connects the centre to the district Fragata and to the highway that goes to the Federal University of Pelotas and the neighbouring city, Rio Grande (about 60 km southeastwards from Pelotas). Thepoints Laranjal (7.9 ± .03), Areal (25. ±3.8), Trem (7.7 ± .35) and Capão do Leão (8.7 ± 2.8) did not exhibit differencebetween each other as well as the points Três Vendas (40.9 ± 3.4) and Centro (42.6 ± 3.7) (ANOVA followed by TuckeyP<0.05). In a comparison, the results obtained by Dallarosa et al. (2008) [6] for the autumn in Porto Alegre were smaller (29.70 μg.m^{-3}) than in Três Vendas and Centro.

Figure 3 shows some important aspects about the evolution of PM2.5 concentration and weather conditions. There was clearly less rainfall accumulate and the wind speed was lower when comparing to summer, which means that there wassmaller wet deposition and advection. On the other hand, the mean concentration of fine particulate matter had a sharpincrease. Excepting for the points Simões Lopes and Laranjal, all the other points seem to have a straight match to thesimultaneously measured points, such as for Três Vendas and Porto, despite their distance. In this sampling, the crossing ofthe 25 μg.m^{-3} occurred over a great part of the time.

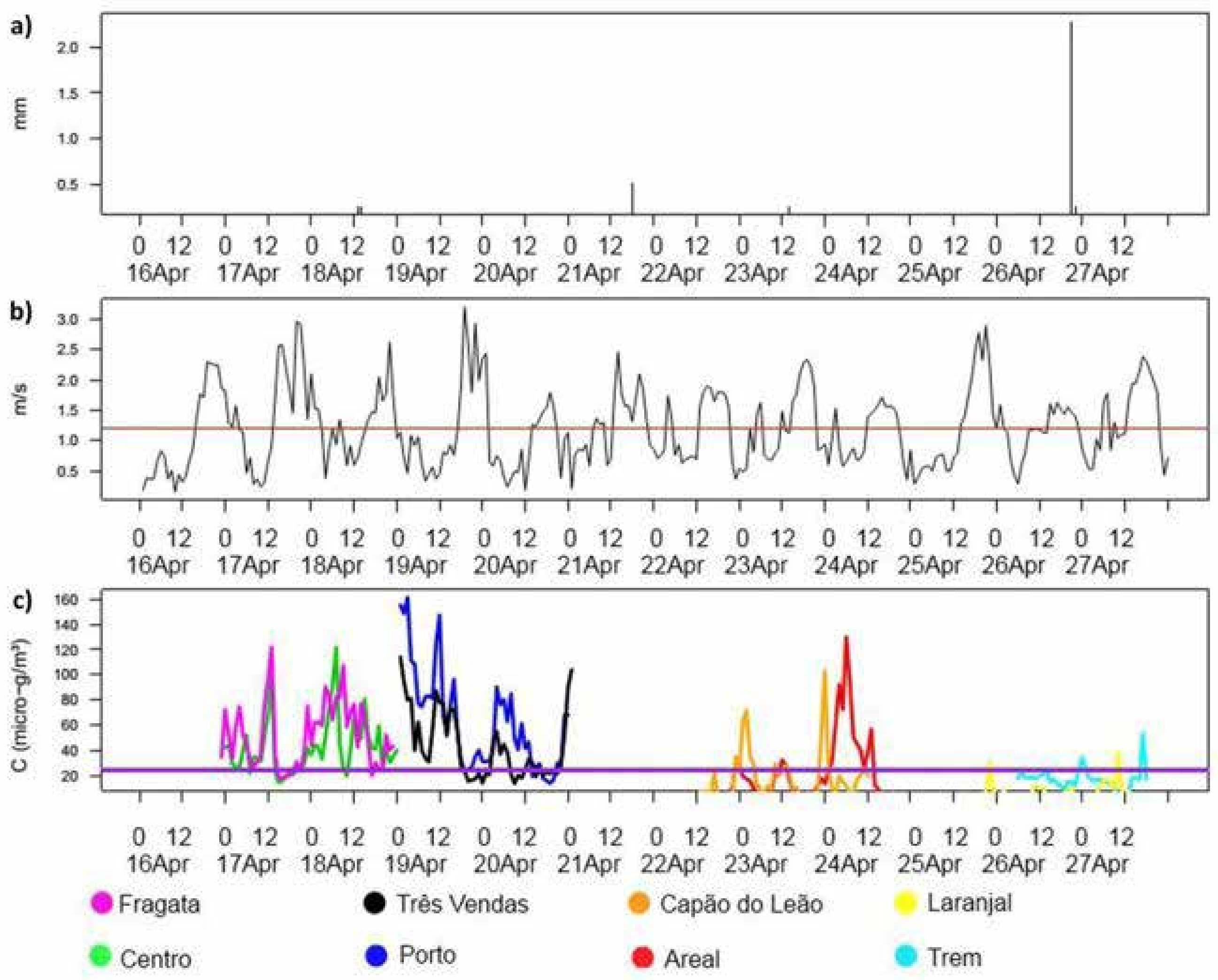

Figure 3: Time evolution for rainfall, wind speed and concentration of PM2.5 in autumn for all points studied.

a) Time evolution for hourly rainfall, **b)** Hourly averaged wind speed (red line for total average) and **c)** Hourly averaged PM2.5 concentration for the monitored points (purple horizontal line for 25 µm.m^{-3}), for the autumn sampling. Hours expressed in Universal Time Coordinate (UTC -Greenwich Meridian Time), Local time = UTC - 2 (autumn) and UTC - 3 for the remaining seasons

In the winter, there is a clear and accentuated increase in PM2.5 concentration, over all the sampling points. The points Laranjal (88.0±7.22) and Porto (84.6 ± 3.9) presented high values of PM2.5, and were statistically different from the points Trem (36.5±4.9) and Capão do Leão (37.69±6.6) (ANOVA followed by Tukey $P < 0.05$), which registered the lowest concentration values, although crossing the 25 µg.m^{-3} WHO recommendation. According to the Air Quality Monitoring Network (FEPAM), the mean concentration in Porto Alegre downtown during the winter of2002 was 09.2 µg m^{-3}. In comparison with Miranda (2002) [1,14], in 2008 the average concentration during the whole winter in Porto Alegre was 9.3 µg.m^{-3}, and in Rio Grande it reached 29.4 µg.m^{-3}. Rio Grande is the most important port city in the state and has one of the most important maritime ports in Brazil. The climate is very similar to Pelotas, it is subtropical and mild, with a strong oceanic influence and relatively cool winters, warm summers and regular precipitation all year.

Data shown in Figure 4 indicate that the referred period of winter was highly favourable to retain pollutants on the lowest troposphere. This is particularly the case in which there is strong atmospheric stability suppress the development of the mixing layer on the ABL during the day (that would be responsible for stirring the layer) and maintaining a strong stable layer closer to the ground at night. This is why the major peaks of concentrations happened during night time (by 0 UTC -9 pm local time). The mean wind speed, just like in autumn, was relatively lower, and there was quite a few rainfalls during the sampling period.

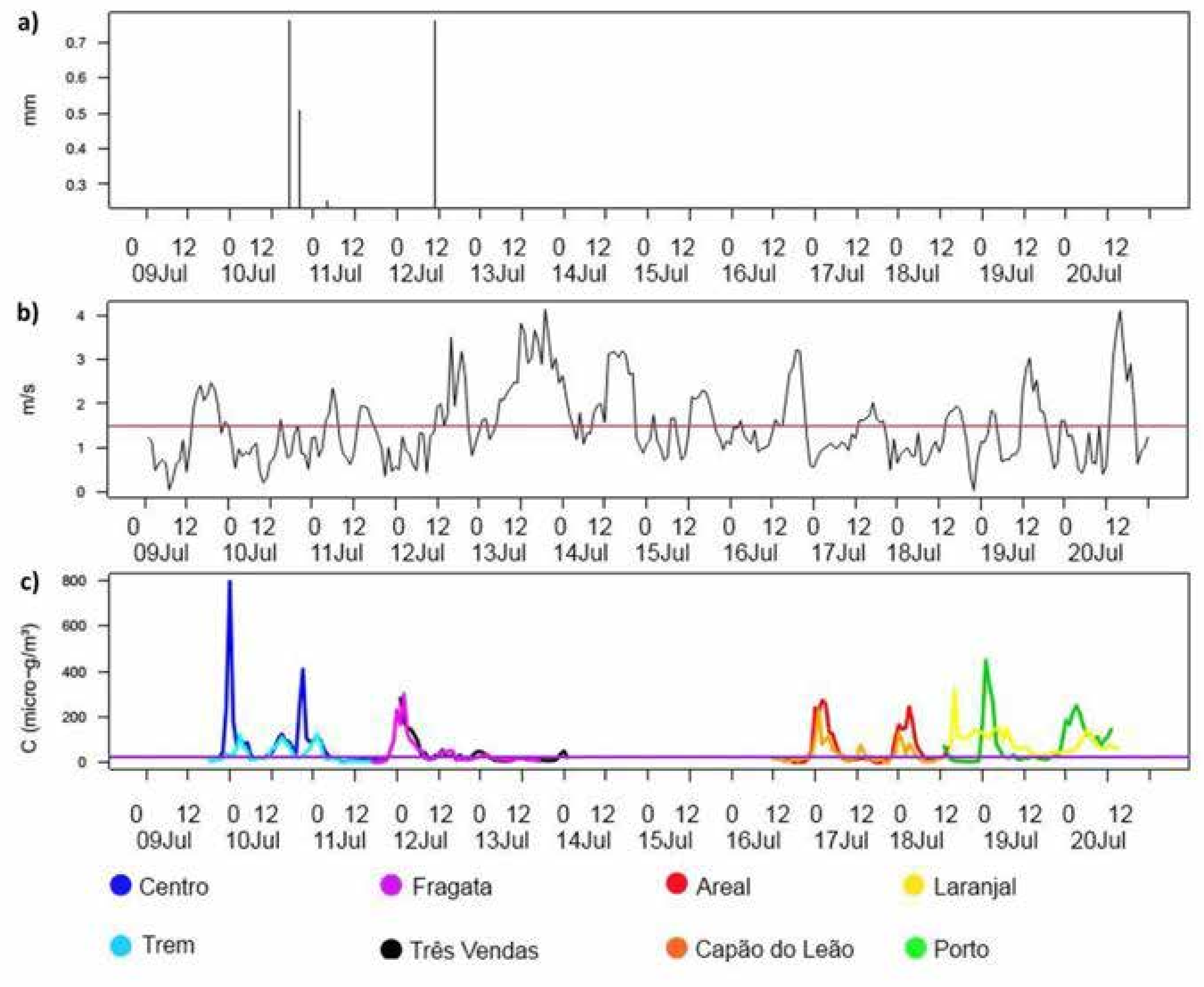

Figure 4: Time evolution for rainfall, wind speed and concentration of PM2.5 in winter for all points studied. **a)** Time evolution for hourly rainfall, **b)** Hourly averaged wind speed (red line for total average) and **c)** Hourly averaged PM2.5 concentration for the monitored points (purple horizontal line for 25 $\mu m.m^{-3}$), for the winter sampling. Hours expressed in Universal Time Coordinate (UTC -Greenwich Meridian Time), Local time = UTC - 2(winter) and UTC - 3 for the remaining seasons

The results from spring show that for the points Três Vendas (29.42±2.53), Capão do Leão (25.2±2.48) and Centro (25.09±6.2), it was registered the greatest concentration crossing the 25 $\mu g.m^{-3}$ WHO boundary. Those pointswere statistically different from the other points (ANOVA followed by Tukey $P < 0.05$). The points Areal (0.29±.05), Simões Lopes (0.63±0.28), Fragata (.28±0.82), Porto (3.66±0.8) and Laranjal (4.22±0.79) presented smaller concentrations and did not differ statistically between each other. According to FEPAM, the mean concentration inthe spring for Rio Grande (mobile sampling station) was computed as 2 $\mu g.m^{-3}$, whereas in Porto Alegre it was 25.98 $\mu g\ m^{-3}$ [6].

Figure 5 indicates that the sampling period in the spring had the greatest accumulate rainfall and mean wind speed among all the other periods. It also depicts a huge variability on the PM2.5 concentration, which remained below the 25 $\mu g/m^{-3}$ value in most of the time, but had extremely high peaks, including two not shown in the point Centro (270 and 90 $\mu g/m^{-3}$, respectively). In agreement to all the other previous experiments we carried out, the concentration peaks occurred all within the first hours in the morning or the first hours in the evening, which are the most intense traffic hours. There is also a clear relationship of inverse proportionality of the pollutant concentration and the wind speed and precipitation.

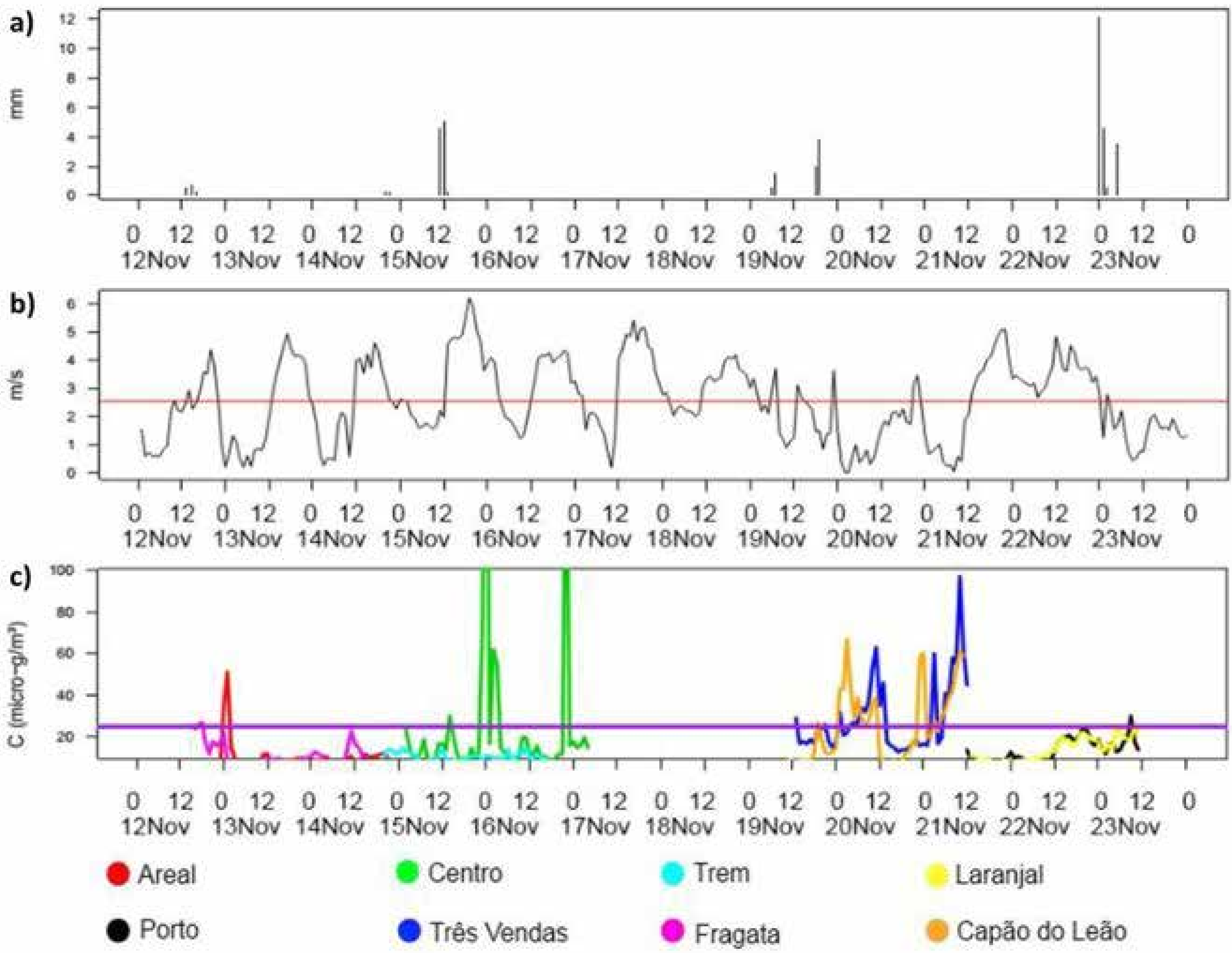

Figure 5: T time evolution for rainfall, wind speed and concentration of PM2.5 in spring for all points studied **a)** Time evolution for hourly rainfall, **b)** Hourly averaged wind speed (red line for total average) and **c)**Hourly averaged PM2.5 concentration for the monitored points (purple horizontal line for 25 $\mu m.m^{-3}$), for the spring sampling. Hours expressed in Universal Time Coordinate (UTC -Greenwich Meridian Time), Local time = UTC -2 (spring) and UTC - 3 for the remaining seasons

The current WHO guideline value of 40 $\mu g/m^{-3}$ (annual mean) was determined to support the public from the health effects of gaseous NO2. The reason for this was that most of the abatement methods specific for NOX are not designed to control other co-pollutants and may even increase their emissions. Accordingly, NO2 is monitored as a marker for complex combustion-generated pollution mixture, thus a lower annual guideline value should be used.

The results of NO2 in the eight points in all seasons of the year are presented in Table 3.

Seasons	Summer		Autumn		Winter		Spring	
Points	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
Porto	0.77	.30	2.26	0.78	9.3	0.89	4.08	.0
Areal	2.92	0.22	7.09	.09	7.39	.6	4.57	.32
Centro	8.86	.24	8.88	0.78	9.0	0.96	9.77	0.58
Fragata	9.26	0.46	34.29	0.78	25.52	0.38	6.70	0.62
Três Vendas	8.86	2.07	28.5	0.82	23.6	0.90	6.8	.0
Laranjal	5.93	4.79	3.35	.92	2.44	0.98	3.63	0.20
Capão do Leão	.60	0.42	4.90	.57	0.8	0.59	9.80	0.48

Table 3: Mean±Standard Errors concentrations of NO2 in the eight points all the seasons ($\mu g.m^{-3}$)

The points that presented the greatest concentration of NO2 ($\mu g/m^3$) in the summer were Centro (8.86±.24) and Três Vendas (8.86±2.07), both within the WHO established values (40 $\mu g/m^3$). The points Areal (2.92±0.22) and Capão do Leão (.60±0.42) were statistically different from the points Porto (0.77±.30), Centro (8.86±.24) and Três Vendas (8.86±2.07), (ANOVA P< 0.05 followed by Tukey). Furthermore, the smallest records for NO2 concentration were in the sites Capão do Leão (.60±0.42), Areal (2.92±0.22), Fragata (9.26±0.46), Simões Lopes (9.00±0.47) and Laranjal (5.93±4.49). According to FEPAM (2006), the concentration of NO2 in the summer in Porto Alegre (47 $\mu g/m^3$) was much higher than in Pelotas.

In the autumn, NO2 data revealed that the great concentration sites were Simões Lopes (36.68±0.8), Fragata (34.29±0.78) and Três Vendas (28,5±0,82), being statistically different from the other points. Nevertheless, none of themrecorded values exceeding the WHO limit. The points Capão do Leão (4.90±.57), Centro (8.88±0.78), Porto (2.26±0.78)and Laranjal (3.35±.92) recorded smaller concentration and did not statistically differ from each other. In 2006, the autumn average of NO2 concentration in Porto Alegre (86 $\mu g/m^3$) was much higher than in Pelotas.

The winter greatest values were reached in the sites Centro (9±2.3), Três Vendas (23.6±2.2), and Fragata (25.52±0.38), but not crossing the WHO standard. In Porto (9. ±2.) and Simões Lopes (0.6±3.9) we observed smallest NO2 concentration, differing statistically from the other points. Data from FEPAM showed that, in 2002, the average NO2 concentration over the central Porto Alegre in the winter was lower (54.2 $\mu g/m^3$) than in the city if Rio Grande (6. $\mu g/m^3$). In the spring, the points Três Vendas (6.8±.0) and Fragata (6.70±0.62) registered the greatest concentrationvalues and were statistically different from the other sites. The sites Laranjal (3.63±0.20), Porto (4.08±.0) and Areal(4.57±.32) had smaller concentration and did not differ from each other statistically. Data from the mobile air quality station in Rio Grande registered in the spring an average concentration of NO2 of 74.3 $\mu g/m^3$, higher than in Porto Alegre (60$\mu g/m^3$), which registered lower concentration values, although crossing the 40 $\mu g/m^3$ WHO recommendation.

Conclusion

We can notice that the different sites studied did not follow a pattern together, that is, there are significant differences in levels of pollution within the same city. Such differences can be due to the characteristics of each region with respect to the traffic of vehicles or other human activities.

The knowledge of pollution dispersion locally applied is tremendously important for the evaluation of the emission impacts. Since there are no indicatives that social and industrial activities drastically change in thedifferent seasons, the highly variable pollution records for each site may be well explained by the differentmeteorological conditions, which may change seasonally or daily with respect to wind, precipitation and other variables. The only exception is for the site Laranjal, where many people spend days or weeks during summer.

Though the experiments were made in short periods and were meant to be representative of a relatively small area, the results obtained in this study clearly indicate that the city of Pelotas as a whole is a potential host forcritical air quality episodes, overall, during winter. The results also show the importance of implementing programs focused on controlling the emissions of fine particulate matter in urban areas.

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