

Traffic-related air pollution in an industrial area

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Abstract

Motor vehicles are a significant source of air pollution and recent studies suggest an association between automobile emissions and increased respiratory symptoms or diminished pulmonary function. In industrial areas – due to the dependence of industries on motor vehicles for the transport of products and workers and because stringent emission controls have been implemented in order to reduce the release of pollutants from the stationary sources – the weight of traffic has been increasing, compared with local anthropogenic sources. The objective of this work was to assess the relation between pollutant concentrations, traffic fluxes and meteorology near the main roadway of an industrial area. During two weeks, air pollution measurements were performed in site X and Y located 7 and 70 meters from this heavy traffic road. A mobile station, located at Site X, measured the pollutants PM₁₀, PM_{2.5}, NO, NO₂, NO_x, SO₂, CO, O₃, benzene, toluene, xylene and PAHs and meteorological parameters. At Site Y, only PM_{2.5} and PM₁₀ were assessed continuously. In parallel, a traffic count was performed in order to get the local vehicle fleet. Results showed positive correlations between traffic and the pollutants NO, NO₂, NO_x, SO₂, CO, xylene and PM₁₀. For PM₁₀ and SO₂; these correlations increased when calculated for heavy duty vehicles instead of total vehicles. This work highlights the complex mixture of pollutants present in the near-road of an industrial area and contributed to the evaluation of the role of traffic emissions with the air quality in the industrial area of Mitrena.

Keywords: *traffic pollutants, industrial area, daily patterns, wind direction.*



1 Introduction

In recent years, numerous epidemiological studies have demonstrated associations between population's proximity to high-traffic-volume roadways and adverse health effects, which include asthma and other respiratory symptoms [1], birth and developmental effects [2], premature mortality [3], cardiovascular effects [4] and cancer [5]. Specific pollutants in vehicle exhaust, including black carbon (BC), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOC) and particulate matter (PM) have been implicated as possible disease-causing agents.

These findings have motivated research to better comprehend the characteristics of pollutants near roadways environments as well as the factors governing the temporal and spatial variations in pollutant concentrations. Therefore, numerous studies have made important contributions to understand the extent and causes of pollutant dynamics near busy roadways or in specific urban environments [6, 7]. However, these works never focused the importance of the traffic for the air quality in industrial areas.

The industrial sector has been implementing stringent emissions controls in order to reduce the release of pollutants from the stationary sources. Therefore, in industrial areas the weight of traffic has been increasing comparing with the local anthropogenic sources, due to the dependence of the industries on motor vehicles for the transport of products and workers. Emissions from motor vehicles led to elevated concentrations of certain air pollutants, including carbon monoxide (CO), nitric oxides (NO_x), nitrogen dioxide (NO₂), coarse (PM_{2.5-10}), fine (PM_{2.5}) and ultrafine (PM_{0.1}) particles and BC, posing problems in the air quality management of industrial areas.

Although traffic emissions are known to significantly contribute to regional air pollution, the understanding of the local-scale near-road impact is complicated by several factors. In addition to pollutant-specific formation processes, other parameters that likely affect near-road air quality include meteorology, traffic characteristics, road design and roadside structures that modify the dispersion of emissions. In industrial sites, the assessment of the traffic contribution is even more challenging due to the multiplicity of emission sources.

The present work is integrated in the project PM_{fugitive} which aimed to assess the contribution of vehicles emissions in a Portuguese industrial region by integrating pollutant measurements, receptor modelling and dispersion modelling. The specific objective of this work was to collect a dataset in an industrial area that reflected the range of temporal scales of air pollutant variation near a roadway over the course of two weeks and to determine the major trends in pollutant concentrations.

2 Methodology

2.1 Site description

Data presented in this study were measured in the industrial area of Mitrena Portugal. Mitrena is an industrial area that coexists with a high-density urban region (Setúbal) and areas with an important environmental concern (Sado Estuary and Arrábida which belongs to the protected area Natura 2000 Network). The main activities located in Mitrena are associated with the local industry (paper, chemical and fertilizer industries) and harbour operations. During two weeks (2nd to 15th February 2013) air pollution measurements were performed in site X and Y located 7 and 70 meters from a heavy traffic road, respectively, 100 meters from the Sado River and approximately 10 km from the Atlantic Ocean (Figure 1). Meteorology during the sampling period was characterized by winds from the 4th quadrant (93% of the time) with an average velocity of 3 m.s⁻¹, 0 mm of precipitation and average temperature and humidity of 11°C and 70%, respectively.



Figure 1: Sampling sites X and Y (1), fertilizer and chemical industries (2), paper industry (3), harbour (4), urban areas of Setúbal (A) and Lisbon (B), protected areas of Sado Estuary (C) and Arrábida (D) and Atlantic Ocean (E).

2.2 Instrumentation for air monitoring

A mobile station, located in Site X, measured the pollutants PM₁₀, PM_{2.5}, NO, NO₂, NO_x, SO₂, CO, O₃, benzene, toluene, xylene and PAHs and meteorological parameters, which included wind speed, wind direction, temperature and humidity. In site Y two VEREWA were used to measure outdoor PM_{2.5} and PM₁₀ concentrations at 2 m from the ground. In both sites, Gent samplers were installed in order to sample particles in two size ranges (PM_{2.5} and PM_{2.5-10}) in four periods per each day. Sampled particles were measured by Instrumental Neutron Activation Analysis (INAA) and Particle Induced X-Ray Emission (PIXE) for element characterization and receptor modelling. Results of particles speciation and receptor modelling will be presented elsewhere. Table 1 presents the instruments used in this study.

Table 1: Instruments used for air monitoring.

Parameter	Instrument	Resolution time	Location
PM ₁₀	VEREWA Beta Dust Monitor F-701-20 Beta radiation absorption	1 hour	Site X
PM _{2.5}	VEREWA Beta Dust Monitor F-701-20 Beta radiation absorption	1 hour	Site X
NO	HORIBA APNA – 360 Chemiluminescence	15 min	Site X
NO ₂		15 min	Site X
NO _x		15 min	Site X
SO ₂	HORIBA APSA – 360 Pulse fluorescence	15 min	Site X
CO	HORIBA APMA – 360 Non-dispersive Infrared Detection	15 min	Site X
O ₃	HORIBA APOA – 360 Ultraviolet Absorption	15 min	Site X
PAH	ECOCHAM PAS 2000 Photoelectric Aerosol Sensor	15 min	Site X
Benzene	HORIBA APSA – 360 Gas chromatography with Photoionization Detector	15 min	Site X
Toluene		15 min	Site X
Xylene		15 min	Site X
Temperature	THIES TDL 14 and VAISALA WXT510 meteorological stations	15 min	Site X
Relative Humidity		15 min	Site X
Atmospheric Pressure		15 min	Site X
Wind Velocity		15 min	Site X
Wind Direction		15 min	Site X
Pluviosity		15 min	Site X
*PM _{2.5} , PM _{2.5-10} , chemical elements	Gent sampler Gravimetry, INAA and PIXE	6:00–11:00 11:00–16:00 16:00–21:00 21:00–6:00	Site X
PM ₁₀	VEREWA-beta radiation absorption	1 hour	Site Y
PM _{2.5}	VEREWA-beta radiation absorption	1 hour	Site Y
*PM _{2.5} , PM _{2.5-10} , chemical elements	Gent sampler Gravimetry, INAA and PIXE	6:00–11:00 11:00–16:00 16:00–21:00 21:00–6:00	Site Y

*Results not included in the present paper.



3 Results and discussion

3.1 Vehicle fleet

Traffic fleet was assessed by counting the number of vehicles per category (motorcycles, passenger cars, heavy duty vehicles and bus) that circulated in the road that is 7 m from site A. Traffic counts were made in a weekday and in a Sunday. On the weekday, traffic volume was significantly higher than during Sunday. In the weekday, the measured number of vehicles was 10,164, of which 17% were heavy duty diesel vehicles. The morning rush hours occurred from 7:00 to 9:00 peaking at 7:00 and the afternoon rush hours from 15:00 to 19:00 peaking at 17:00.

From 8:00 to 19:00 the number of heavy duty vehicles was stable with an average of 114 vehicles per hour. On Sunday, a total of 2667 vehicles were measured of which only 4% were heavy duty vehicles. A similar daily pattern was observed characterized by two peaks.

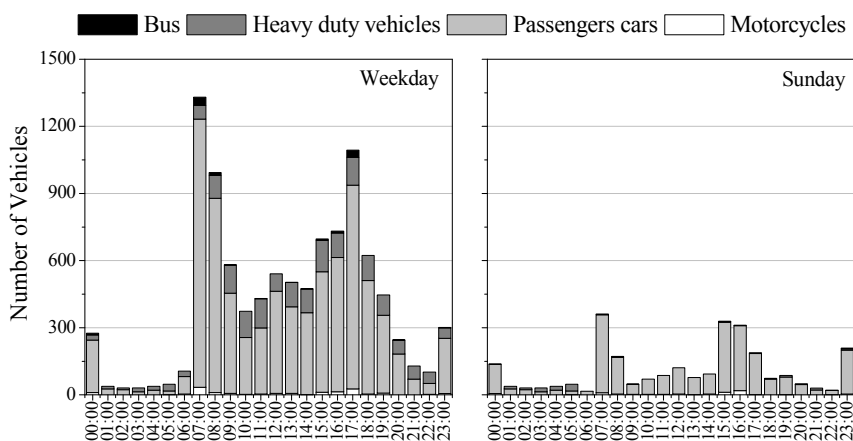


Figure 2: Hourly traffic volume for a weekday and a Sunday.

3.2 Pollutant concentrations

Figures 3, 4, 6, 7 and 8 present the hourly average concentrations for the measured pollutants and showed that there was a significant diurnal variability in multiple pollutants.

Correlation coefficients between pollutant concentrations and total number of vehicles were calculated with no regard to meteorological or other parameter. Results showed correlations only for weekdays and for the pollutants NO (0.69), NO₂ (0.69), NO_x (0.72), SO₂ (0.44), CO (0.51), xylene (0.42) and PM₁₀ (0.29) in site X. Correlation were also calculated for heavy duty vehicles instead of total vehicles and an increase was observed of the correlations for PM₁₀ (0.66) and

SO₂ (0.78), indicating the importance of these vehicles emissions not only associated with vehicles exhaust but also with the re-suspension of dust.

At weekdays, daily patterns of PM₁₀ concentrations were characterized by three peaks. Maximum PM₁₀ concentrations occurred in the periods 9:00–12:00 (67 $\mu\text{g.m}^{-3}$); 16:00–18:00 (67 $\mu\text{g.m}^{-3}$) and 0:00–1:00 (64 $\mu\text{g.m}^{-3}$), while the maximum traffic density was registered in the period 7:00–8:00 (1330 vehicles) and 17:00–18:00 (1094 vehicles). Borrego *et al.* [8] analysed PM₁₀ concentrations monitored through the Portuguese air quality measuring network between 2001 and 2007 and also verified the existence of an evening PM₁₀ peak. Zhu *et al.* [9] also observed higher PM₁₀ concentrations during the night-time comparing with what it would be expected considering the decrease of traffic density and attributed them to a combination of higher vehicle speeds, lighter winds, decreased air temperature and increased relative humidity during this period. PM₁₀ concentrations measured at Sundays (average 30 $\mu\text{g.m}^{-3}$) were significantly lower comparing with the weekdays (average 49 $\mu\text{g.m}^{-3}$). PM₁₀ presented a significant decrease in local Y principally during the weekdays.

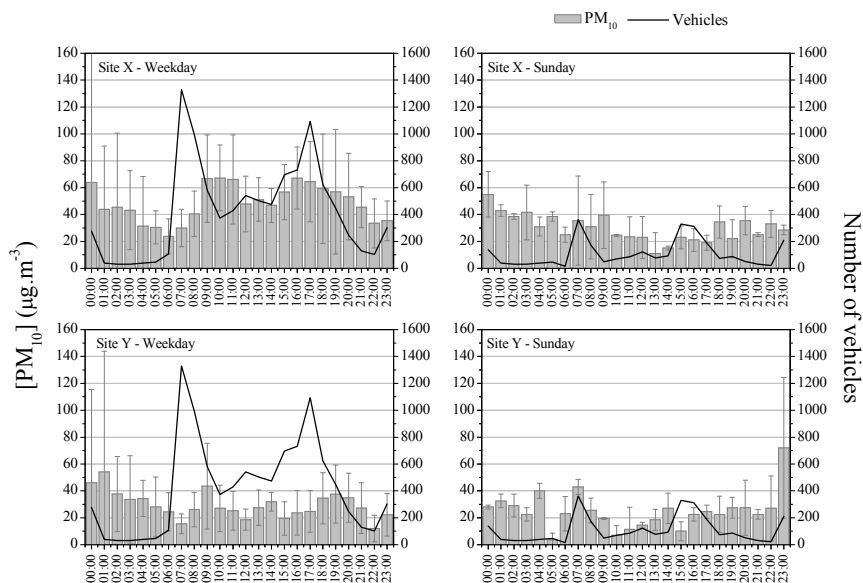


Figure 3: Hourly PM₁₀ average concentrations (for site X and Y) and vehicles number for weekdays and Sundays.

Figure 4 shows that PM_{2.5} not only presented less diurnal variability but also was less affected by the distance to the road (as PM_{2.5} concentrations in site X and Y were not significantly different). The different behaviour found for PM₁₀ and PM_{2.5} can probably be attributed to the fact that coarser particles are principally primary particles associated with soil re-suspension and tyre and break wear, while finer particles result mainly from gas to particle reactions [10, 11].

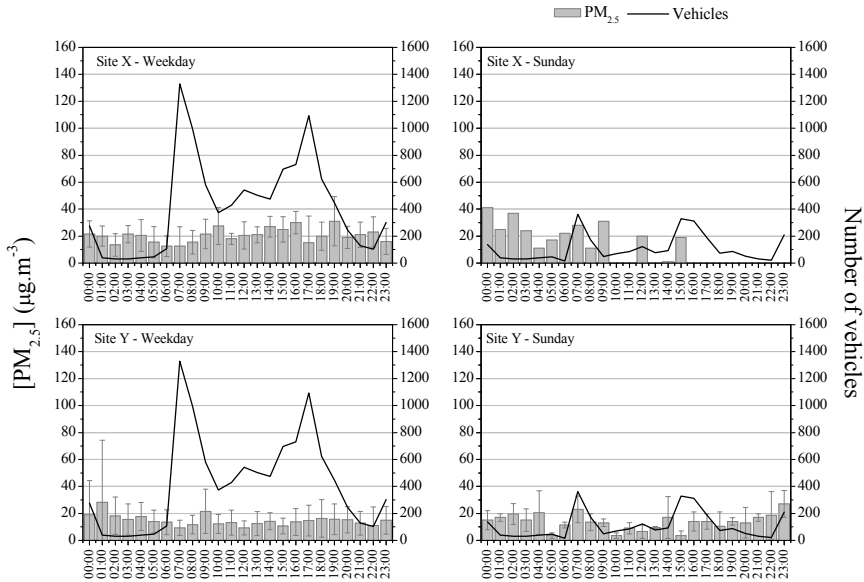


Figure 4: Hourly $PM_{2.5}$ average concentrations (for site X and Y) and vehicles number for weekdays and Sundays.

Figure 5 presents the average pollutant concentration per wind sector and shows that higher PM_{10} and $PM_{2.5}$ concentrations were registered for 330° and 0° , respectively, which corresponded to the road influence. $PM_{2.5}$ presented other peak for 210° that is probably associated with the boats influence, which park 100 m from the sampling site in this direction.

Figure 6 shows the temporal concentrations of nitric oxides were highly dependent on the momentary traffic flows. Similar to the diurnal variation of traffic volume, maxima of nitric oxides concentrations were observed on weekdays and during the rush hours (8:00–9:00 and 17:00–18:00) and minima on Sundays and at night-time. These results showed that in this region these pollutants are mainly affected by traffic. Pollution roses presented in Figure 5 showed that NO , NO_2 and NO_x presented a common behaviour characterized by higher concentrations for winds coming from the road (1st and 4th sector).

Besides having a positive correlation with traffic during the weekdays, SO_2 and CO presented less diurnal variability comparing with nitric oxides. Moreover, the decrease of traffic at Sundays was not accompanied by a decrease of SO_2 and CO concentrations. Pollution roses for these two pollutants also showed the influence of other sources located at southeast and southwest from the sampling point, which are the local industry and the boat traffic, respectively. These results indicated that, in this region, these pollutants are not predominantly associated with road traffic.

Ozone concentrations also varied throughout the day and were characterized by two peaks during the weekdays. The first one occurred between 3:00 and 4:00

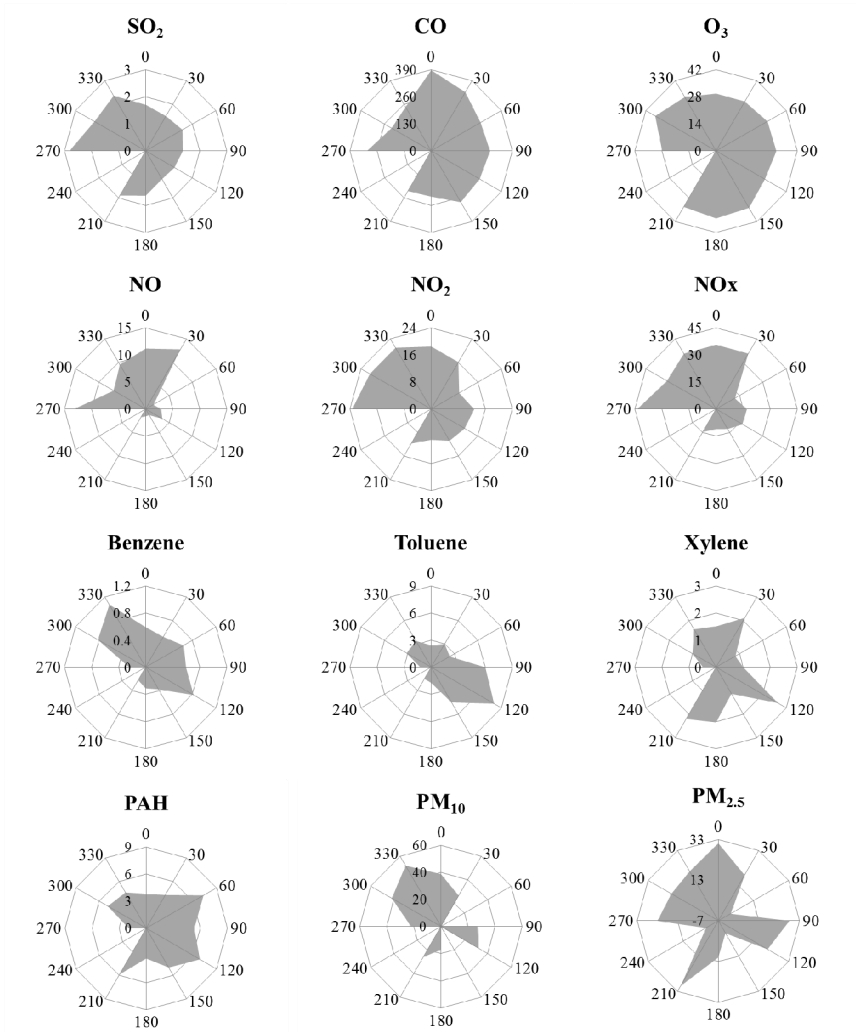


Figure 5: Average pollutant concentration measured in site X per wind sector (values in $\mu\text{g}\cdot\text{m}^{-3}$, except for PAHs, which are in $\text{ng}\cdot\text{m}^{-3}$).

and it was not expected once during the night no photochemical reactions occur. However, analyzing the wind direction for this period, it was verified that 90% of the measurements were associated with winds providing from the urban area of Setúbal. Therefore, probably ozone was produced during the day, in the urban area, and then transported to Mitrena. The second peak occurred after the peak in vehicle traffic and nitric oxides concentration. In Sundays, when the traffic in the city of Setúbal is expected to decrease, it was observed the decreased of O_3 concentrations after sunset, when no more sunlight initiates O_3 formation.

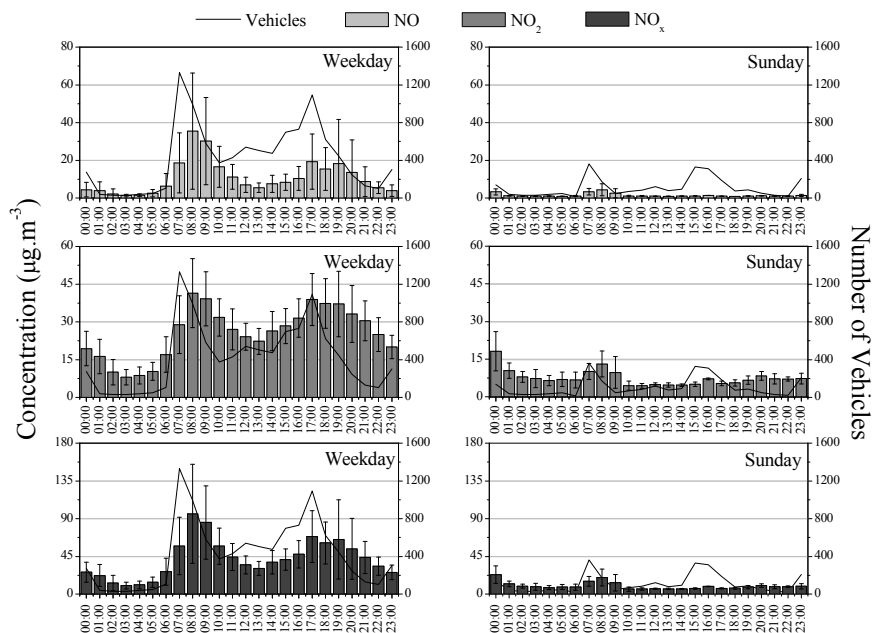


Figure 6: Hourly NO, NO₂ and NO_x average concentrations and vehicles number for weekdays and Sundays.

Benzene, toluene and xylene average concentrations were found to be $0.90 \pm 0.86 \mu\text{g.m}^{-3}$, $3.3 \pm 3.0 \mu\text{g.m}^{-3}$ and $1.3 \pm 1.9 \mu\text{g.m}^{-3}$, respectively. This trend has been commonly observed in VOC traffic related studies primarily because toluene concentration in gasoline is routinely higher than that of benzene and xylene [12]. The average toluene/benzene ratios calculated from vehicle exhaust emission concentrations by Kalenge *et al.* in [12] varied between 2.26 and 4.49. These vehicle emission ratios are similar to the ambient average ratios measured in weekdays (3.93). During Sundays the ratio toluene/benzene increased to 12 indicating the existence of higher emissions of benzene during weekdays. Toluene and xylene concentrations presented higher diurnal variability because they are more photochemically reactive than benzene [12].

Pollution roses for benzene, toluene and xylene presented a common peak for the direction 120° probably associated with the local industry. In addition, benzene presented other more intense peaks for the direction 330° which corresponds to the traffic influence and xylene presents a peak for the direction 210° which corresponds to the boats' influence.

PAHs did not present significant diurnal variations during the weekdays and presented higher concentrations in Sundays. The pollution rose for PAHs shows that higher concentrations were registered for 60°, 120° and 210° indicating the influence of local industry and boats for these pollutants.

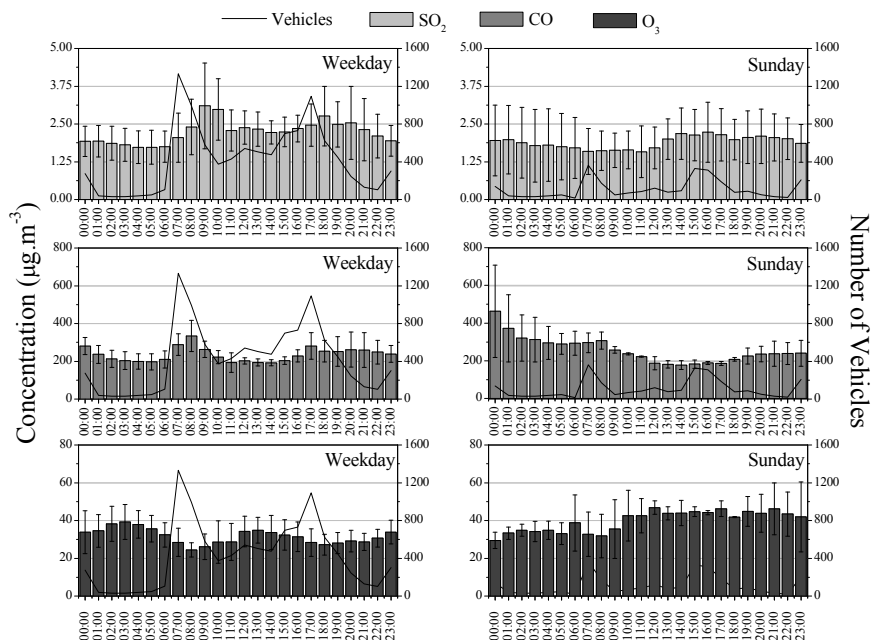


Figure 7: Hourly SO_2 , CO and O_3 average concentrations and vehicles number for weekdays and Sundays.

4 Conclusion

This work highlights the complex mixture of pollutants present in the near-road of an industrial area and focused on the general relationship between pollutant concentrations, traffic fluxes and meteorology. Results indicated that the NO , NO_2 and NO_x concentrations increased with the daily traffic activity, decreased at Sundays and presented peaks for winds from the road. The pollutants SO_2 , CO, xylene and PM_{10} also presented a positive correlation with traffic and this correlation increased, for PM_{10} and SO_2 , when only heavy duty vehicles were considered, indicating the importance of these vehicles emissions not only associated with vehicles exhaust but also with the re-suspension of dust. However, elevated concentrations of these pollutants near the road occur not only when winds were coming from the road, suggesting that these pollutants have additional sources in the studied area.

Results obtained within this work will be integrated with data on particles chemical characterization performed within this study, in addition with receptor and dispersion models in order to assess the contribution of traffic emissions in this industrial area.

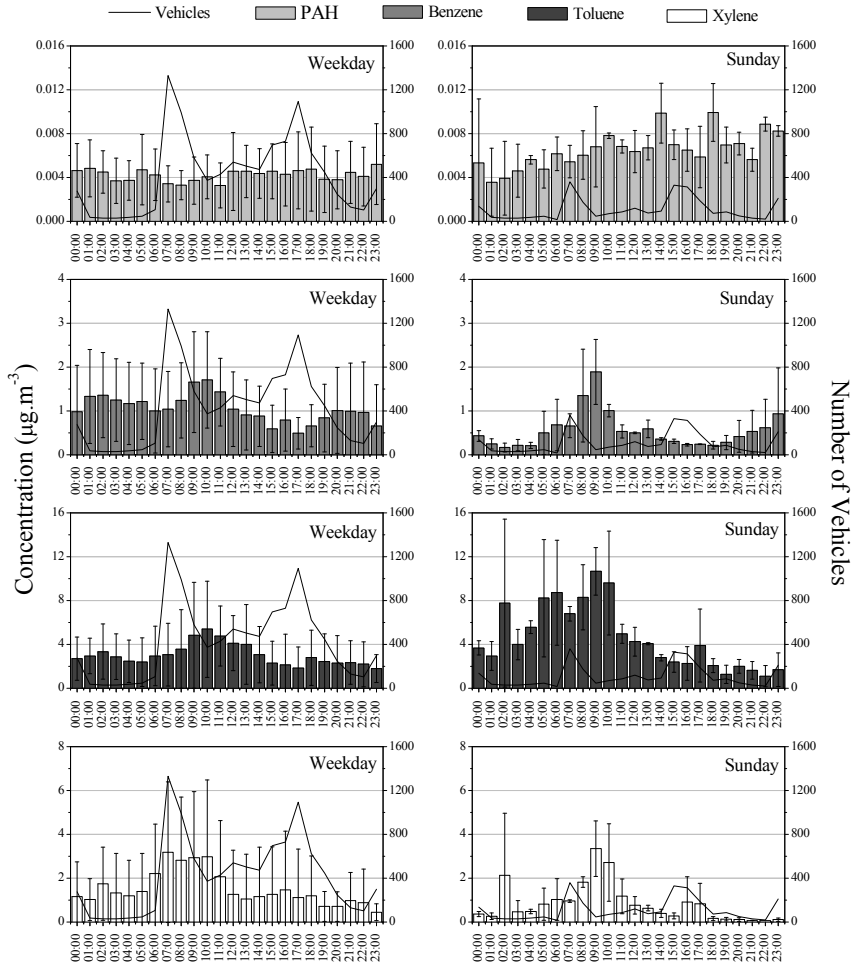


Figure 8: Hourly PAHs, benzene, toluene and xylene average concentrations and vehicles number for weekdays and Sundays.

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