COMPREHENSIVE AIR QUALITY MANAGEMENT OF THE METROPOLITAN AREA OF PORTO

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ABSTRACT
The metropolitan area of Porto, involving several municipalities in the Northern region of Portugal with a total population of more than 1.5 million inhabitants, is one of the Portuguese agglomerations where air quality limit values were surpassed and the assessment and suggestion of strategic measures to improve urban air quality is an urgent issue. This air quality evaluation should not only focus the classical pollutants, like carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen mono and dioxide (NO and NO_2), ozone (O_3) and particulate matter with an aero-dynamical equivalent diameter lesser than 10 μm (PM_{10}), but also cover trace compounds, namely heavy metals, dioxins and furans and polycyclic aromatic hydrocarbons (PAH).

Keywords: air quality management, PM_{10}, O_3, dioxins and furans, PAH, Porto

1. INTRODUCTION

Most of industry and traffic is concentrated in urban areas, which are home to almost 80% of the European population. Although emissions from motorised vehicles and large point sources have been reduced through the use of cleaner fuels and technology, urban areas still show increasing signs of air quality degradation (Fenger *et al.*, 1998). In 1996, the European Union (EU) adopted the Framework Directive 96/62/EC on ambient air quality assessment and management. Under this legal framework member states have to control and monitor the concentrations of certain pollutants in the atmosphere. If certain air quality standards are surpassed, member states have the obligation to prepare plans and programs that must indicate measures to improve air quality and to comply with specified limit values.

The main purpose of this paper is to analyse the available air pollutants data in the metropolitan area of Porto towards the contribution to a comprehensive air quality management of this Portuguese agglomeration.

2. AIR QUALITY IN PORTO

During the last 5 years an air quality-monitoring network has been under construction in metropolitan area of Porto. At present, 13 monitoring stations are in regular operation (see Figure 1).

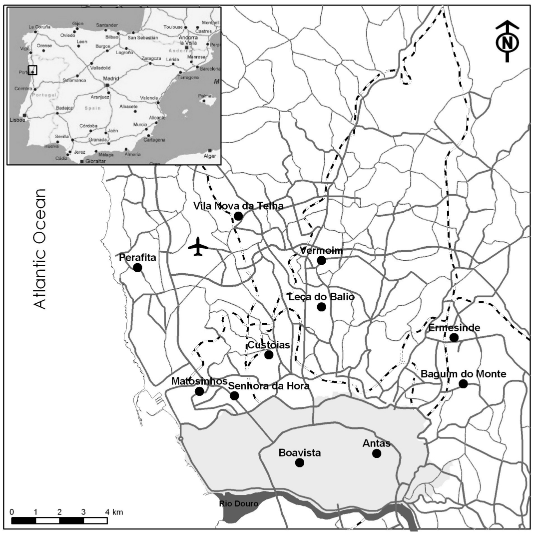

Figure 1. Layout of the air quality-monitoring network of the metropolitan area of Porto. The monitoring stations of Vila do Conde and Espinho are located outside de geographical domain of this map.

Simultaneously, and as a consequence of a monitoring program of a new municipal waste incinerator initiated in 1998, a large database of atmospheric levels of heavy metals (Ni, Cd, As, Hg, Cr, Cu, Mn, Pb and Zn), as well as dioxin and furans has been collected. More recently, regular monitoring of PAHs was initiated.

The existence of this comprehensive data set allows to fully characterizing the air quality *status* in the region of Porto, not being limited by the typical interpretation solely based in regulatory pollutants.

2.1 PM_{10}

The analysis of the data sets of PM_{10} indicates that there is a systematic exceeding of air quality standards for this pollutant, in a significant number of monitoring stations independently from being traffic-oriented or background. These episodes are a combination of several factors dominated by traffic and local emissions, background concentrations and meteorological conditions. The contribution of natural sources is also an important issue, mainly in south-european cities (Rodriguez *et al.*, 2001; Querol *et al.*, 2004) that has to be evaluated.

2.1.1 Natural contribution

The possibility of occurring natural contamination with mineral dust is important to study at larger spatial scale. In fact, one of the most pointed out causes for the occurrence of natural dust particle episodes in southern Europe, and in particular in the Mediterranean basin, has been airborne dust carried from northern Africa (Sahara and Sahel deserts). This scenario might be responsible for extraordinary peak situations. However, an increase of background levels may occur every time air masses are originated form the inner peninsular or northern Africa.

Considering the location of the traffic stations such as Boavista and Antas, it is possible that a decisive factor in measured PM_{10} levels and high number of exceeding situations occurred in 2002 may either be due to dust resuspension from soil due to wind (Chaloulakou *et al.*, 2003).

To confirm these assumptions, a study to test dependencies of PM_{10} levels with wind speed and relative humidity was performed (Coutinho *et al.*, 2005a). Pollution roses considering 10 m height wind direction were built for each air quality station. As an example, the Senhora da Hora station pollution rose for 2002 is presented in Figure 2. This pollution rose reveals the presence of a marked sector, where higher concentrations characterise the air arriving from the East (99^{th} percentile is 180 $\mu g.m^{-3}$). In average terms, a more marked effect is observed in the presence of East-Southeast winds, where PM_{10} average levels rise to 90 $\mu g.m^{-3}$. This suggests the existence of long-range dust transport, namely Saharan dust.

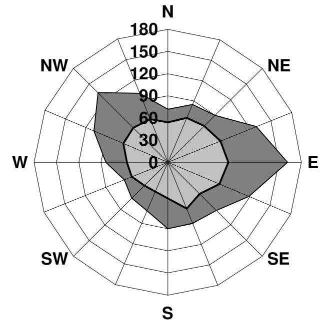

Figure 2. PM_{10} pollution rose (average (light grey) and 99^{th} percentile (dark grey)) for Srª da Hora, with 10 m height wind direction.

The possible contribution of sea spray to the increase of particle levels in the Porto region can equally be assessed with the study of pollution roses. Figure 2 reveals also another marked sector for peak levels with Northwest wind (99^{th} percentile is 120 $\mu g.m^{-3}$). This NW peak clearly corresponds to the presence of sea air masses.

In Portugal, each summer, forest wildfires are another source of PM_{10} to the atmosphere. Backward trajectories analysis (Borrego *et al.*, 2005) confirmed that Porto urban area was clearly affected by forest fires emissions, which are one of the main contributors to the high measured levels of this pollutant during summer episodes.

2. 1. 2 Anthropogenic local sources

In urban areas like Porto, PM_{10} emissions are due to combustion associated to residential, industrial and traffic processes. Also turbulence generated by passing traffic generates dust ressuspension (Ketzel *et al.*, 2005). Moreover, several monitoring stations in Porto had been under the strong influence of construction works in their proximity throughout 2002.

Stronger winds lead to greater land erosion and consequent scattering of dust accumulated near large construction sites. Although admitting that the existence of a strong correlation with wind speed would be an indication of local sources, this assumption was not confirmed since the assessment of the data revealed that there wasn't any significant correlation with wind velocity.

2. 1. 3 Thermal inversions

Aiming to better understand the PM_{10} sources contribution to the air pollution episodes a phenomenological analysis was developed with a strong incidence on the relation between episodes and thermal inversions (Coutinho *et al.*, 2005a).

The innumerable PM_{10} exceeding cases occurred on cold winter days can be associated with the thermal inversion phenomenon, which occurs mainly in large urban centres (Artiñano *et al.*, 2003). Figure 3 assesses the correlation between hourly PM_{10} concentrations registered from January to March 2002, at a background station (Leça do Balio) and the temperature gradient for the layer between ground level and an altitude of 200 m, obtained through modelling. The importance of atmospheric stability in episodic PM_{10} contamination phenomenology is quite clear. It is evident that at all situations where concentrations over 150 µg.m^{-3} were observed, occurred in stable circumstances, when temperature gradient was greater then -1ºC/100 m.

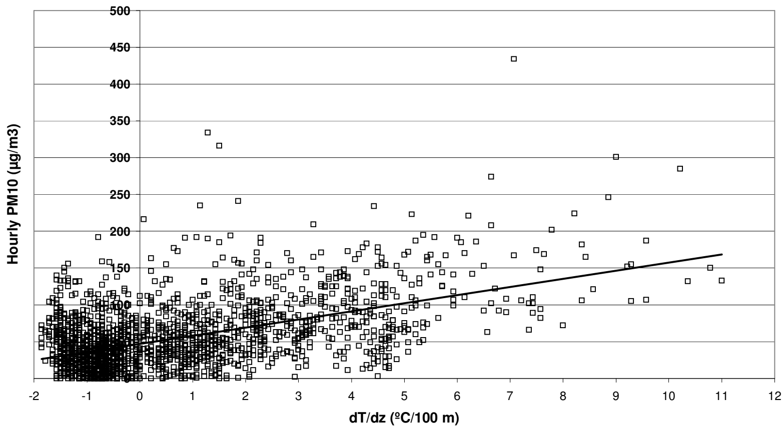

Figure 3. Correlation between atmospheric concentrations of PM_{10} and temperature gradient.

It must be pointed out that this interpretation not only shows the importance of the vertical structure of the low troposphere in the dispersion of atmospheric pollutants, but also the contribution that surface emitting sources, probably of non-industrial origin, are able to have on the degradation of air quality.

2.2 Ozone

Monitoring data obtained in the region of Porto during the last 5 years show that this region is regularly affected by episodes with high levels of tropospheric ozone especially during hot summer days. Geographical patterns follow a typical spatial distribution with lower levels in the urban centre (annual average below 30 µg.m^{-3}) and higher concentrations in the suburbs (annual average close to 50 µg.m^{-3} at 15 to 20 km from downtown).

Figure 4 with the O_3 concentration field estimated by an air quality system of models (Salmim *et al.*, 2005) supports this O_3 spatial pattern.

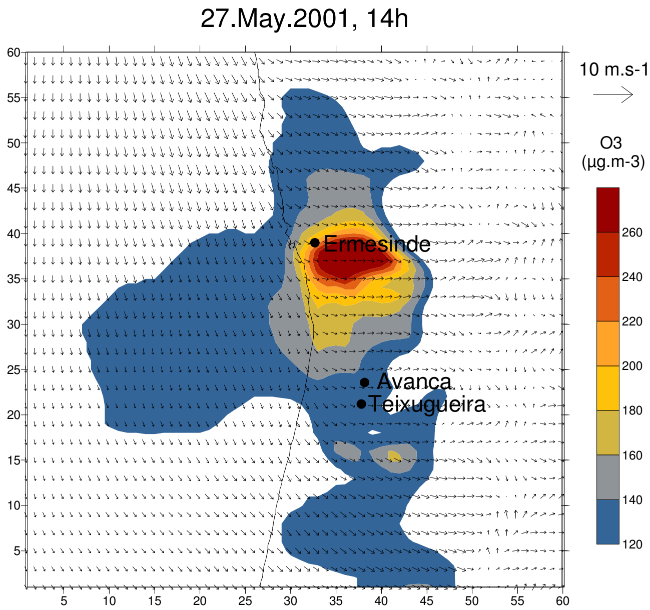

Figure 4: Hourly-averaged O_3 concentration values at 2 pm, for an ozone episode day (Salmim *et al*., 2005).

Application of legal standards included in the EU Directive 2002/3/EC relating to ozone in ambient air reveals that the alert threshold (240 $\mu g.m^{-3}$) was exceeded in 2003 during one hour in three different monitoring stations. Exceeding of the information threshold (180 $\mu g.m^{-3}$) occurs more systematically: 6 monitoring sites were affected by this problem (see Figure 3). The highest number of exceedances occurred in V.N. Telha, a station located 15 km north of the urban centre of Porto. These situations were registered in May, June and August of 2003 and typically happen between 11h00 to 16h00. Standard used as long-term objective for the protection of human health (8 hr average below 120 $\mu g.m^{-3}$) was violated in all of the monitoring stations of the region.

2.3 Dioxins and Furans

The construction of a municipal solid waste (MSW) incinerator in the region of Porto in 1998 led to the development of an external environmental monitoring program (Coutinho *et al*., 2001). This monitoring program includes the regular sampling of dioxins (PCDD) and furans (PCDF) in several matrices such as ambient air, water, sediments, soil, vegetables and diary products. This monitoring program is currently in regular operation. Since the beginning of this program a total of approximately 100 ambient air samples were collected in several sites in the vicinity of the MSW incinerator providing an extensive characterization of dioxins and furans atmospheric levels in the metropolitan area of Porto, as well as information about the temporal trend of the atmospheric concentration of these compounds.

According to Lohmann and Jones (1998), PCDD/F concentrations for the total sum of I-TEQ are typically as follows: remote <10 fg m^{-3}; rural ~20–50 fg m^{-3}; and urban/industrial ~100–400 fg m^{-3}. In Porto, 77% of samples collected are in the 40 to 400 fg I-TEQ m^{-3} range, approximately four times higher than the Lisbon levels (Coutinho *et al.*, 2005b). Levels measured in Porto are consistent with data published for Barcelona, on the NE coast of the Iberian Peninsula, where the reported maximum concentrations were in the range of 600 to 800 fg I-TEQ m^{-3} (Abad *et al.*, 2004).

In the first trimester of 2001 the emission scenario in Porto experienced a significant reduction in the level of dioxins due to the shutdown of two medical waste incinerators responsible for an important fraction of the dioxin input to the atmosphere. Analysis of this data shows that the improvement of air quality in the region was observed either on the overall level of dioxins and furans as well as in subtle alterations of the homolog pattern of these compounds in the atmosphere (Coutinho *et al.*, 2005c).

To determine the existence of a seasonal behaviour of PCDD/F in Porto, two periods were considered, April-September and October-March, referred to as "summer" and "winter" in all figures presented in this paper. Fig. 5 shows the average PCDD/PCDF concentration, expressed in I-TEQ, considering summer and winter periods in the region of Porto.

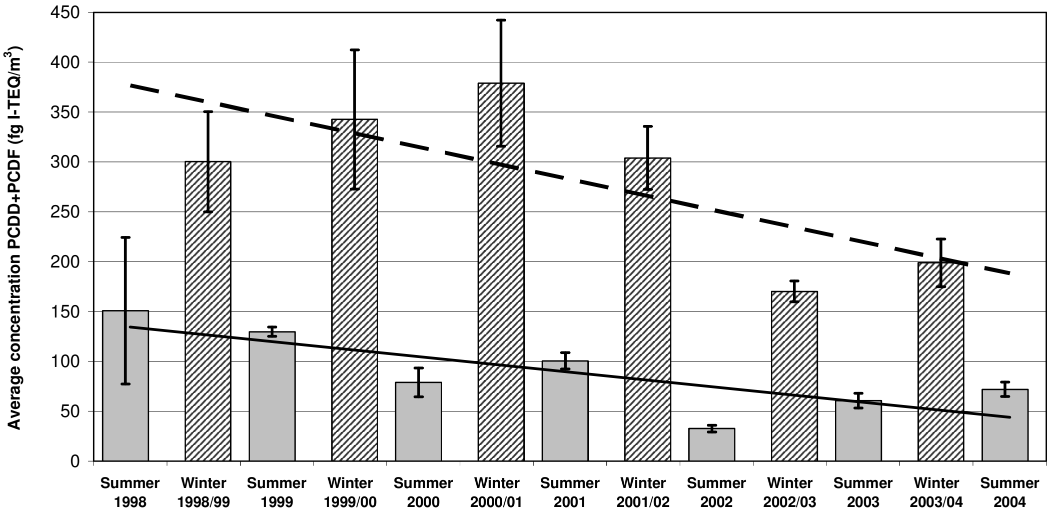

Figure 5. Seasonal average atmospheric levels of PCDD/F in the region of Porto including standard deviation bars and trend line for winter (continuous) and summer (dashed) samples.

Prior to the winter of 2001-02, winter levels in Porto were approximately 3 to 4 times higher than summer levels. After then it is possible to observe a significant decrease of mean concentrations of atmospheric PCDD/PCDF. The mean value (37 fg I-TEQ m^{-3}) and concentration range (13-42 fg I-TEQ m^{-3}) for Summer 2002 are the lowest recorded in this region, followed by Summer 2003 (mean: 50 fg I-TEQ m^{-3}, range: 9,8-172 fg I-TEQ m^{-3}). The decrease of atmospheric concentrations of PCDD/F was

more evident during winter time: PCDD/F levels showed a reduction by a factor of 2, from average levels typically above 300 fg I-TEQ m^{-3} to values between 150 and 200 fg. I-TEQ m^{-3}.
The seasonal pattern can be explained by the intensification of the operation of diverse combustion sources during winter as well as by the more frequent presence of thermal inversion layers at the surface level during winter. These inversions cause a significant increase of atmospheric concentrations when pollutants are emitted at low levels below the thermal inversion layer.

Nevertheless, atmospheric levels of dioxins and furans are still significantly higher than concentrations found in similar airsheds. Probably, ferrous and non-ferrous metal industries located in the region might be partially responsible for these levels.

2.4 Metals

As consequence of the monitoring program designed for the follow-up of the environmental performance of the MSW incinerator, regular measurements of the atmospheric levels of metals (Pb, As, Cd, Ni, Hg, Mn, Cu, Cr and Zn) were performed in the stations of Leça do Balio and V.N. Telha. Samples were taken on a weekly base for all metals except for Lead that was monitored 15 days per month. This field work was initiated in 1998 with sampling of total suspended particles (TSP); starting on the last trimester of 2004 high-volume samplers were adapted for PM_{10}.

Table 1 summarizes data obtained in this monitoring program from 2002 till present. Levels listed as typical correspond to the 90th percentile of each pollutant for that period. Data presented for PM_{10} should be interpreted with additional care due to the limited number of samples (~10) when compared to TSP (>100). Results obtained indicate that there are not exceedances of the EU standard for Pb or for the target value for As, Cd and Ni. At this stage it is significant to mention that the majority of the samples present levels of Ni and Cd below the analytical limit of detection (LD).

Table 1. Typical and maximum levels of metals measured in TSP and PM_{10}.

Concentrations ($ng.m^{-3}$)	TSP typical	TSP maximum	PM_{10} typical	EU standard
Pb	80	420	70	500[§]
As	4	65	4	6[**]
Cd	0.6 (<LD)	8.7	0.6 (<LD)	5[**]
Ni	3 (<LD)	61	3 (<LD)	20[**]
Hg	1	7.2	1	
Mn	45	180	20	
Cu	400	830	120	
Cr	6	20	5	
Zn	1000	2580	700	

[§] Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air.
[**] EU Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air.

A comparison between levels of metals measured in TSP and PM_{10} suggests that As and Hg appear mostly in the PM_{10} fraction opposed to the distribution of Cu, Mn and Zn which are concentrated in the coarser fraction.

2.5 PAHs

Since October 2004, monitoring activities in Leça do Balio and V.N. Telha include the monthly sampling of polycyclic aromatic hydrocarbons (PAH). Seventeen chemical species are determined through analytical procedures including benzo(a)pyrene (BaP), benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-C,D)pyrene, dibenzo(ah)anthracene and fluoranthene (FA) as suggested by the EU position paper in PAH (EU, 2001). Analysis of rethene was also included in the analytical procedure with the aim of acting as a tracer of wood combustion.

Measured concentrations reveal a overpassing of the 1 $ng.m^{-3}$ target value for BaP in one third of the samples with a measured maximum of 1.7 $ng.m^{-3}$. Nevertheless, average concentrations of BaP for the total of the samples range between 0.6 and 0.8 $ng.m^{-3}$. Data available up to the moment is not yet sufficient to verify the compliance to the target value recommended by the EU.

A preliminary interpretation of the cross-correlation between the several PAH included in this study suggests the existence of three different categories:

- Naphthalene: common PAH found in numerous petroleum products, cigarette smoke, wood smoke, tar and asphalt (Irwin et al., 1997);
- A group of PAH including rethene, FA, anthracene and fluorene: these compounds occur ubiquitously in products of incomplete combustion and might be associated with wood combustion, either from residential origin in the winter or from forest fires in the summer;
- A complex group of several PAH highly correlated with BaP: most important sources of BaP emissions are small combustion sources (coal and wood), as well as aluminium and coke industrial sources and diesel engines (AEA Technology, 2001).

3. CONCLUSIONS

A comprehensive air quality management of an urban area, as the Porto agglomeration, should encompass different pollutants and different strategies. Not only regulatory pollutants have to be addressed.

There is a trend to attribute all the urban air pollution problems to road traffic exhaust emissions. This could be true for certain pollutants, like CO or NO_x, but PM_{10} or dioxins and furans can be due to small point sources. Data obtained in Porto indicate that minor industrial sources or practices such as residential wood combustion and backyard trash burning might have a key role on local air quality.

These kind of activities emit pollutants near the ground, they are not elevated sources, giving rise to air pollution episodes in thermal inversion conditions. The definition of measures to improve air quality has to seriously address this issue of small sources of air pollutants, distributed by all the urban area.
Moreover, air quality assessment should also consider the seasonal behaviour of air pollutants, which is strongly related to meteorological conditions. Low humidity, high temperatures and solar radiation, which are frequent at summer season, will promote O_3 episodes and also are associated to the occurrence of forest fires that emit O_3 precursors and PM_{10} to the atmosphere. Low humidity and strong winds, from east and south are related too to forest fires and to dust transport.

Surface thermal inversions are more usual at cold winter days/nights avoiding the dispersion of pollutants emitted by the surface sources and contributing to air pollution episodes.

In consequence, meteorological and air quality forecasts should be seen as important and fundamental tools to short-term air quality management. Long-term measures could include actions like (Borrego *et al*., 2005):

- the promotion of the best available technologies in the industries;
- the reduction to a minimum of heavy-duty vehicles circulation in the urban centres;
- the effective control of emissions from the construction activities;
- the replacement of current wood fireplaces by natural gas centralised residential heating;
- the introduction of low-emission urban public transportation vehicles;
- the promotion of the use of these low-emission vehicles.

This scenario indicates that planning an air quality management strategy that includes the correct identification of specific measures to tackle the full problem is not obvious for the "big solution". Instead, the solution will be the overall sum of many "small measures", involving a large number of stakeholders. Air quality managers will have to integrate in their plans and programs, knowledge about IPPC best practices on small industries as well as educational measures to change current attitudes of citizens concerning mobility and domestic activities in order to implement a comprehensive air quality management strategy.

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