3

Air Pollution Impact on Asthma and Bronchitis in Porto, Portugal, During the Year 2005

Azevedo, J.M.F. and Gonçalves, F.L.T.
Astronomy, Geophysics and Atmospheric Sciences Institute, São Paulo University, Brazil

1. Introduction

Air pollution is currently one of the most studied areas, which has gained importance due to the adverse effects caused to public health from exposure to certain compounds. Ozone (O_3) and particulate matter (PM) with aerodynamic diameter less than 10 micrometres and 2.5 micrometre (PM_{10} and $PM_{2,5}$) are pollutants associated with asthma attack events. The long duration of exposure to O_3, PM_{10} and nitrogen dioxide (NO_2) has been associated with chronic respiratory disease and reduced lung function, and with increased incidence of colds (Gilmour et al. 2006; Trasande and Thurston, 2005 ; Brunekreef and Holgate, 2002)

In São Paulo, Brazil, Saldiva et al. (2008) found that vascular and pulmonary diseases are associated with long-term exposure to air pollution. Putting the hypothesis that inflammation of the lung epithelium and endothelium, resulting in airway and vascular pathology, are due to exposure to polluted air.

Besides the geographical and climatological characteristics, the urban pollution sources play an important role on air quality. According to a study (Fontes, 2005) on the impact in urban air quality of road traffic, in 2000, 41% of emissions in the Porto Metropolitan Area was due to transport. These accounted for 39% road transport

In southern Europe the experience accumulated since 1986 shows that problems of air quality depend on the meteorological meso-scale, the diurnal cycle and spatial scale of tens of kilometers (Lalas et al 1983, Millan et al. 1984, 1987).

In the area of the Western Mediterranean, the high ozone concentrations are often associated with high pressure systems at the synoptic scale and formation of low heat. The low pressures induce the convergence of flows to the peninsula which forces the sea breeze to flow (Castell, 2006).

According to Gonçalves et al. (2006, 2010), the relationship between respiratory and cardiovascular diseases, the meteorological variables and the thermal indices is large, mainly by stress caused by cold. The result of this study to Sao Paulo showed that morbidity from cardiovascular and respiratory diseases is seasonal.

In the Iberian Peninsula (IP), the 6 warmest years have occurred in the last 12 years. The year 2004 was the 18th consecutive year with minimum temperature above average 1961-1990, according to the Portuguese Institute of Meteorology (IM). For example, on the 6th and 7th of June in Porto, Pedras Rubras weather station recorded a deviation of 14.8°C above the average for the season (summer). In an analysis of decades, the decade of 2000-2009 was drier than in 1990-1999 and it was drier than the previous two decades. There was a decrease in rainfall from 1970 to 939 in the 70 mm to 779 mm in the 2000s. This corresponds to an average annual loss of about 160 mm (Meteorological Institute of Portugal, 2010). Note that the winter of 2004/05 was the driest of the last 79 years. This scenario, coupled with low humidity and precipitation, increased the forest fire incidence in the summer.

On the other hand, taking a large scale view, the last months of 2004 (October, November and December) and the first months of 2005 saw the development of the phenomenon called El Niño in the Pacific Ocean. This phenomenon is characterized by significant short-term changes (12 to 18 months) in the distribution of the Pacific Ocean water surface temperature. The El Niño of 2004-2005 was considered of low intensity compared with the year 2002-2003 (Lyon, 2005). Its impact can be felt all over the world, with high or low intensity. The Iberian Peninsula and, as consequence, Portugal region, can feel the impact of El Niño/Southern Oscillation (ENSO) variability (Melo, 2005; Rocha, 1998, 1999) mainly as low seasonal precipitation. As a consequence, air pollution is largely influenced by large-scale weather conditions. According to Azevedo et al (2011) the 2005 summertime high ozone concentration was positively associated with cardiovascular and NO and CO pollutants were correlated with respiratory diseases, in the Porto Metropolitan Area.

This work deals with an ecological time series study. AB diseases were considered as the dependent variable and the meteorological variables and air quality have worked as independent variables. Descriptive statistics, correlation models between variables and lag structures, as well as factor analysis by principal components were used to perform the analysis.

2. Material and methodology

Porto Metropolitan Area is located in the Northwest of Portugal (41.08°N and 8.40°W), in the Iberian Peninsula. The population of Great PMA is about 1 608 000 people. The study area has Mediterranean climate with maritime influence. That means that the winter season is wet and cool and the summer season is dry and hot. The difference in temperature, humidity and precipitation, between the seasons implicates a physiological adaptation, as well as, technological and clothing choice.

Thermal comfort in both summer and winter are important for public health. Especially, children, elderly, and people with diseases belonging to risk groups require specific care (Simões, 2003; Neuberger, 2004).

To understand the seasonal impact on respiratory diseases (RD) such as asthma and bronchitis (herein thereafter named as AB), the year 2005 was selected. Meteorological aspects relevant to a global level make this year interesting for study.

2.1 Material

Daily data from different institutions was used as the basis for this study:

- The health data from four administrative database PMA hospitals:

Hospital Geral de Santo António (Porto city), Hospital Pedro Hispano (Matosinhos), Hospital Valongo (Valongo) and Hospital de São João (Porto East). The morbidity studied is classified as 490-496 from CID 9th revision. The medical information is administrative data from hospital admission through the entrance for the emergency service.

- The air quality selected stations were:

Vermoim, Perafita, Senhora da Hora, Matosinhos, Vila Nova da Telha, Antas, Baguim, Custóias, Leça, Boavista and Ermesinde. The stations measure photochemistry pollutants, carbon monoxide (CO), inhalable (coarse) particulate matter (PM_{10}) and sulfur dioxide (SO_2). The only station to measure fine particulate matter $PM_{2.5}$ is Vermoim (see Figure 1.). The air pollutants database is hourly and it can be found for download in the website (http://www.qualar.org). The ozone concentration is an 8-hourly composite average and the PM date is based in the lag of 7 hours. Daily mean was calculated from the data series, except for the O_3 that used the daily maximum. All the data are shown in $\mu g/m^3$.

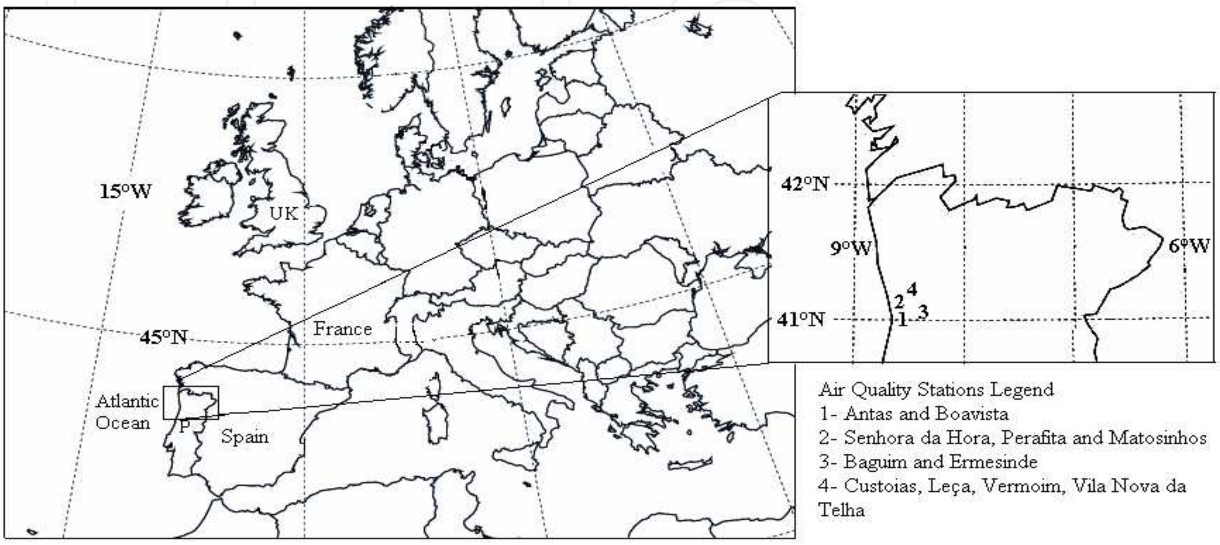

Fig. 1. Western Europe map (left). North Portugal map (right) with the Air quality Stations grouped by numbers according to the legend (right below). Between the numbers 2 and 4 is the meteorological station Pedras Rubras.

Meteorological parameters from "Instituto de Meteorologia" (Portuguese Meteorological Institute) Pedras Rubras station (Figure 1), with the following variables: Air temperature (maximum, Tmax; mean, Tmean; minimum, Tmin)(°C), Relative Humidity (Hr) (%), Precipitation (mm) and wind velocity (m/s)

2.2 Statistical methodology

The methodology chosen was the time series for an ecological study. In this type of study, as the hypothesis, the independent variables (air pollutants and meteorological variables) are factors which influence the morbidity either partially, in group or individually (the dependent variable).

The statistical analysis was based on weighted values, considering Custóias as the geographically central station with the greatest weighted value, 0.50, followed by Leça and Senhora da Hora 0.25, Antas, Matosinhos and Vermoim, 0.15, Baguim, Vila Nova da Telha, Boavista, Ermesinde and Perafita, 0.10. This weighted time series was constructed using arithmetic means. This choice was was based on major correlation (>0.70, $p<0.05$) between the stations that measure each pollutant. If the missing data is large, as for the variable CO, only arithmetic means were used.

Statistical tools applied to the health, meteorological and air quality data were: descriptive statistics (average and maximum), Pearson correlation coefficient calculus, time-lag structure and Principal Components Analysis. The softwares *Excel 2003* and *Statistica* 7.0.61.0 and *SPSS* 17.0 were used in the calculation.

2.2.1 Pearson correlation coefficient

Pearson coefficient correlation varies between -1 and +1. If the coefficient is equal -1 mean that the correlation is perfectly negative, however correlation equal to +1 values represent prefect positive correlations. Results equal to zero represent no correlation.

2.2.2 Factorial analysis although Principal Component Analysis

As it is well known, analysis although Principal Component is a multivariate technique in which a number of related variables are transformed in a smaller set of uncorrelated variables (e.g. Jackson 1991). The technique rewrites the original data matrix into a new set of components that are linearly independent and ordered by the amount of the variance they explain. Therefore the component weights calculated express the correlation between the original variables. The procedure adopted consisted of grouping in the same component parameters those with the same temporal variability. A correlation matrix is determined having as input air pollutants and meteorological variables. The RPCA technique started with the calculation of the *eigenvalues* and *eigenvectors*, and the matrix of the correlation coefficients between the variables. This methodology has been applied to identify the sources of air pollution since early 70's, as described in Hopke (1991).

2.2.3 Lag structure

The symptoms after air pollution exposure and high low air temperatures could be evident some days later. On the other hand, many people with respiratory diseases go to the hospital only after acute respiratory event. According to Lin (2008) to understand the relationship between exposure and symptoms it is important to use the lag structure. In this study was used 2 and 3 days lag. This method used 1 to 3 days anticipation.

2.3 Wind effective temperature

Thermal comfort is essential to maintain human health. When somebody is relaxing or in hard sport activity the thermal comfort is a factor that determines the major or minor human organism performance, efficiency and health impacts. Many authors are developing some mathematic equations involving 2 or more correlated meteorological variables depending on the propose of the study. The indices aim to identify the physiological sensitivity limits. These equations measure the body's compartmental oscillation when exposed to different meteorological parameters.

The index selected for this study measures the "Effective Temperature in Wind function" (TEv). This index calculates the thermal sensation of air temperature that is perceived depending on wind magnitude and relative humidity, according to Suping et al. (1992) as it follows:

$$TEv = 37 - \frac{(37 - t_{air})}{[0.68 - 0.0014UR + \frac{1}{1.76 + 1.4v^{0.75}}]} - 0.29t_{air}(1 - \frac{UR}{100})$$

Where: t_{air}= air temperature (°C)
UR= relative humidity (%)
v= wind velocity (m/s)
TEv= Effective temperature in wind function (°C)

3. Results and discussion

As already mentioned in the introduction the year 2005 presents some meteorological characteristics different from other years. Although it was considered of low intensity, in the study area this has resulted in a surplus of precipitation below the previous and subsequent years (Table 1)

Year	Annual Precipitation (mm)	May –Sep Precipitation (mm)
2003	1374	172.9
2004	978.2	258.7
2005	609.2	101.5
2006	974.1	169.6

Table 1. Annual and May-September precipitation (mm) to Porto Area.

To facilitate understanding and to better organize the results presentation, these will be divided into winter and summer period.

3.1 Wintertime

According to the '*Instituto de Meteorologia de Portugal*' (Meteorology Institute of Portugal, MIP) in 2005 was recorded the lowest rainfall total since 1931. The annual average air temperature in 2005 was 15.6 °C, +0.6 °C above the mean value considering the period 1961-1990 (http://www.meteo.pt). This scenario led to some problems in various economic sectors.

With regards to air temperature, the months of January and February were characterized by a cold wave, also reported by the MIP (Figure 2.).

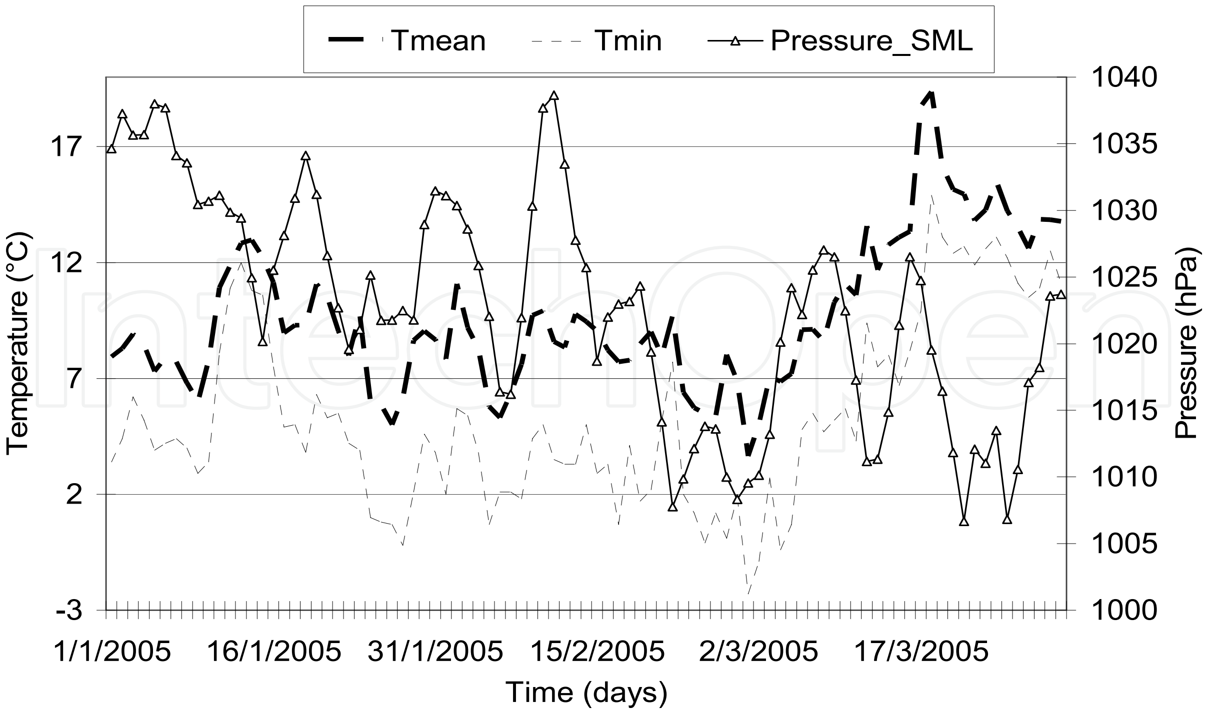

Fig. 2. Mean and minimum daily air temperature (Tmean, Tmin, respectively) and sea mean level pressure (Pressure_SML)

Variables		**Asthma/Bronchitis'**
O_3	Pearson Correlation	0.009
	Sig. (2-tailed)	0.867
	N	365
PM_{10}	Pearson Correlation	0.014
	Sig. (2-tailed)	0.794
	N	362
SO_2	Pearson Correlation	0.031
	Sig. (2-tailed)	0.556
	N	365
NO	Pearson Correlation	**0.218****
	Sig. (2-tailed)	0.000
	N	365
CO	Pearson Correlation	**0.179****
	Sig. (2-tailed)	0.001
	N	362
NO_2	Pearson Correlation	0.090
	Sig. (2-tailed)	0.087
	N	365
$PM_{2.5}$	Pearson Correlation	0.039
	Sig. (2-tailed)	0.468
	N	355
Precipitation	Pearson Correlation	-0.014
	Sig. (2-tailed)	0.796
	N	365
Tmean	Pearson Correlation	**-0.228****
	Sig. (2-tailed)	0.000
	N	365
Pressure_SML	Pearson Correlation	**0.228****
	Sig. (2-tailed)	0.000
	N	365

Table 2. Analysis of 'annual Pearson correlation (2005)' between meteorological variables and air quality, considering the AB disease as dependent variable. Correlation is significant at the $p<0.01$** level (2-tailed) and $p<0.05$* level (2-tailed).

During the winter, in general, and in this specific case, the days that have increased pressure have clear skies and low temperatures. As in the days with low atmospheric pressure there may occur precipitation and cloudiness. The cloud cover during the days of low pressure allows a 'greenhouse effect' located. While the clear sky in days of high pressure allows the radiactive heat loss, despite the existence of the sun, decreasing the minimum temperatures.

During the year 2005, there is significant and positive association between AB diseases and pollutants NO (0.218, $p<0.01$), CO (0.179, $p<0.01$) and the atmospheric pressure (0.228, $p<0.01$) and negative relationship with mean air temperature (-0.228, $p<0.01$).

The winter of 2004-05 began with low precipitation values (0 mm until 12 January) as illustrated in Figure 3. However, the concentration of PM_{10} during the periods without rain, increased to more than double (maximum 183.6 μg/m^3) of the average value (44.1 μg/m^3), this represents a concentration 30 times higher than the minimum value, 6.2 μg/m^3. The Air Quality Index measures the degree of degradation of air quality, according to the European Policy. For the interval 35-49 μg/m^3 classification is 'average'. Above 49 μg/m^3 air quality is poor and more than 119 μg/m^3 is bad.

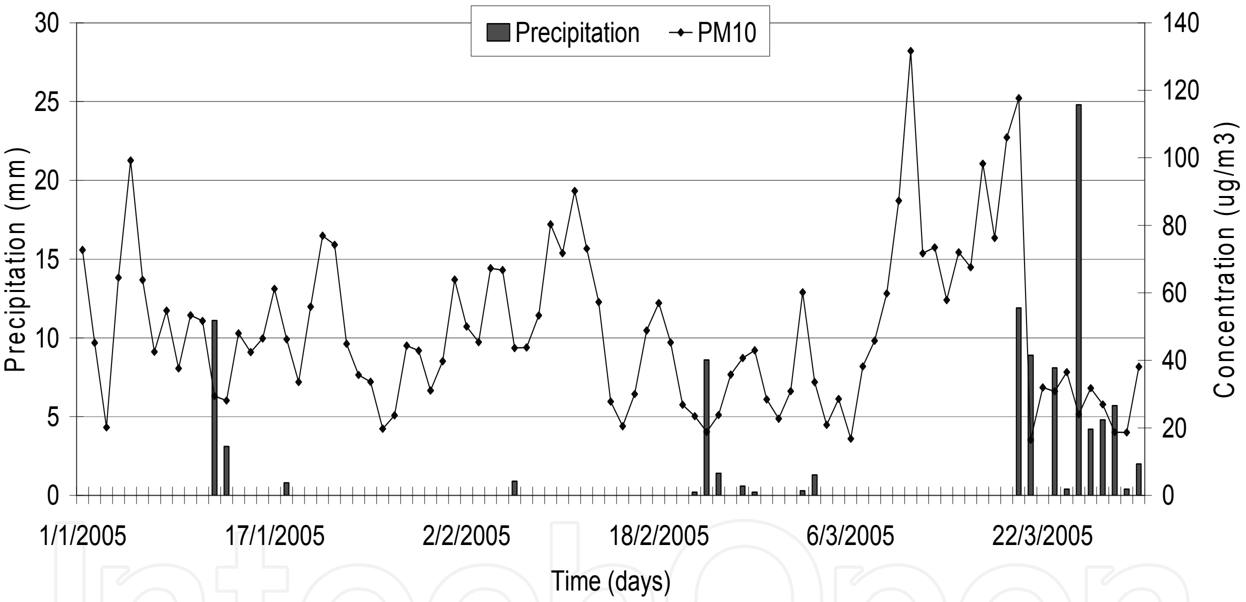

Fig. 3. Daily precipitation (mm) and PM_{10} daily mean concentration (μg/m^3) during 2005 January to March.

The concentration of PM_{10} may increase with the absence of precipitation, i.e., with decrease in rainfall (negative correlation, -0.30, $p<0.05$). Moreover, according to Gao et al. (2007) concentration of ozone increases due to higher solar radiation, photochemical reactions between air components and ozone precursors. The increase in tropospheric ozone, during this period of January and February, was related to the diseases as shown in Table 3. In factor 2, explaining 24% of variance, even having a low communality value (0.25), AB diseases (0.46) are clearly positively associated with Wind Effective Temperature (TEv) (0.96 and 0.97), and negatively with ozone (-0.50). According to Gonçalves, et al. (2005) thermal comfort indices associate more than 1 variable (actually three) in just one variable, which decrease the variability and increase the explanation of the variance, explained by this variable.

Variables	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**
O_3	**-0.46**	**-0.50**	0.41	0.63
PM_{10}	**0.95**	0.12	0.10	0.92
SO_2	0.24	0.03	**0.89**	0.84
NO	**0.88**	0.08	0.25	0.84
CO	**0.95**	-0.02	0.06	0.90
NO_2	**0.73**	0.15	**0.54**	0.85
$PM_{2.5}$	**0.91**	0.09	-0.01	0.84
Asthma / Bronchitis'	0.21	**0.46**	-0.07	0.25
TEv_Tmin_Hrmin_Vmax	-0.10	**0.96**	0.15	0.94
TEv_Tmin_Hrmax_Vmax	-0.01	**0.97**	0.05	0.95
Expl.Var	4.26	2.37	1.35	
Prp.Totl	0.43	0.24	0.13	

Table 3. January and February 2005 factor extraction through the Principal Component Analysis. VARIMAX rotation method.

Through factor analysis of principal components is verified that the variation of PM_{10} (0.95) concentration is identical to the variation of the pollutants: NO (0.88), NO_2 (0.73), CO (0.95) and $PM_{2.5}$ (0.91) and partially opposite to the ozone (it appears with negative sign).

The variable (TEv) was introduced in the PCA to adjust the air temperature at the effective temperature, considering the wind contribution. The wind speed decreases the temperature felt by the human body (Stathopoulos, 2006). For the Port region the difference between the absolute minimum air temperature and values of effective temperature considering the wind speed is over 10° C (Table 7).

Considering the three months of winter (January-March) using a lag of one and two days we have identified significant correlations ($p < 0.05$ or $p < 0.01$) among the diseases studied and some pollutants (Table 4 and 5).

In both statistical methods (factor analysis and correlation analysis) the ozone is associated negatively with disease (-0.5; 1 day lag, -0.23, $p < 0.05$, respectively).

According to Joseph (2007) the tropospheric ozone is formed by photochemical reactions between oxygen and its precursors (NO and NO_2) for days with little cloud cover and high solar radiation. When night falls the tropospheric ozone is converted in their precursors. Thus, during the day ozone concentration increase and the ozone precursor's concentration decrease. At night the inverse occurs. As the ozone, its precursors are respiratory irritants to the mucous.

Variables	**1 day lag**	**Asthma/Bronchitis'**
PM_{10}	Pearson Correlation	0.166
	Sig. (2-tailed)	0.109
	N	94
$PM_{2.5}$	Pearson Correlation	0.155
	Sig. (2-tailed)	0.136
	N	94
O_3	Pearson Correlation	**-0.233***
	Sig. (2-tailed)	0.024
	N	94
CO	Pearson Correlation	**0.209***
	Sig. (2-tailed)	0.043
	N	94
TEv_Tmin_Hrmin_Vmax	Pearson Correlation	-0.030
	Sig. (2-tailed)	0.774
	N	94
NO	Pearson Correlation	**0.234***
	Sig. (2-tailed)	0.024
	N	94

Table 4. January-March Person Correlation with 1 day lag. Correlation is significant at the 0.01** level (2-tailed) and 0.05* level (2-tailed).

Variables	**2 days lag**	**Asthma/Bronchitis'**
PM_{10}	Pearson Correlation	0.190
	Sig. (2-tailed)	0.068
	N	93
$PM_{2.5}$	Pearson Correlation	**0.241***
	Sig. (2-tailed)	0.020
	N	93
O_3	Pearson Correlation	**-0.213***
	Sig. (2-tailed)	0.041
	N	93
CO	Pearson Correlation	**0.219***
	Sig. (2-tailed)	0.035
	N	93
TEv_Tmin_Hrmin_Vmax	Pearson Correlation	-0.030
	Sig. (2-tailed)	0.776
	N	93

Table 5. Pearson correlation January-March 2005 with 2 days lag. Pondered mean values from all stations. Correlation is significant at the 0.01** level (2-tailed) and 0.05* level (2-tailed).

3.1.1 Particular case

In this topic, the analysis of the winter period was reduced, comprising, only, the two months of lower precipitation (January-February). In addition, two air quality stations were chosen for correlation analysis applying lag.

As explained in paragraph 2.2 of this paper, the statistical analysis was based on the weighted average daily concentrations of pollutants measured in different seasons. This strategy facilitates the statistical calculations and covers the study area satisfactorily. However, for some stations the concentration values are masked. The correlation values may be higher when considering each station separately, as shown in Table 6.

Table 6 shows significant correlation with values of PM_{10} and $PM_{2.5}$ concentrations to Vermoim station (1 day lag: PM_{10}, 0.362, $p<0.05$, and $PM_{2.5}$, 0.292, $p<0.05$; 2 days lag: PM_{10}, 0.430,$p<0.430$,$p<0.01$, and $PM_{2.5}$, 0.354, $p<0.01$) and Matosinhos stations (PM_{10}, 1 day lag, 0.331, $p<0.01$; 2 days lag, 0.283, $p<0.05$).

Variables		1 day lag Asthma broanquittis	2 days lag Asthma/Bronquittis
$PM_{2.5}$ Vermoim	Pearson Correlation	**0.292***	**0.354****
	Sig. (2-tailed)	0.023	0.006
	N	61	60
PM_{10} Vermoim	Pearson Correlation	**0.362***	**0.430****
	Sig. (2-tailed)	0.028	0.009
	N	37	36
PM_{10} Matosinhos	Pearson Correlation	**0.331****	**0.283***
	Sig. (2-tailed)	0.010	0.030
	N	60	59

Table 6. Pearson correlation to 2005 January and February months. Correlation is significant at the 0.01** level (2-tailed) and 0.05* level (2-tailed).

When the time series of pollutants are averages of several stations the significant correlation results are low as those of tables 4 and 5. However, the correlation results can be considered significant because they are consistent with average values for each station separately.

3.2 Summertime

During the summer, temperatures were high and also low rainfall occurred. For example, table 7 shows the values of temperature (maximum 38°C) and precipitation (total 8 mm) as well as the values of thermal sensation during the period of June to August (summer) 2005.

PCA (Table 8) considering only the hottest summer month, August, associates, in the second factor, the DR with SO_2 (0.77) and NO_2 (0.81) with 19% variance explained, while the first factor, with a total of 50% explained variance, corresponds to the remaining pollutants and air temperature (0.84).

The pollutants found in the first factor are typically associated with combustion of organic matter. During the summer of 2005, a great number of forest fires occurred around the country, and especially near the study area, which decreased air quality in the region (Azevedo, 2011).

2005 June - August Descriptive Statistics

Variables	N	Minimum	Maximum	Mean	Standard Deviation	Variance
TEv_Tmax_Hrmin_Vmax (°C)	92	9.35	27.32	16.47	4.30	18.53
TEv_Tmin_Hrmin_Vmax (°C)	92	-1.24	13.66	5.35	3.15	9.92
Prec (mm)	92	0.00	8.10	0.29	1.14	1.29
Tmax (°C)	92	19.60	38.00	25.34	4.65	21.64
Tmin (°C)	92	11.10	24.30	16.12	2.52	6.34
Valid N (listwise)	92					

Table 7. Descriptive statistic of meteorological variables and TEv, during 2005 June to August (daily absolute values). Where 'N' is the number of analyzed cases, 'Standard Deviation' is the difference compared with the mean and 'variance' is the measure of dispersion around the mean of the series.

Variables	**Factor 1**	**Factor 2**	**Communality**
O_3	**0.94**	-0.09	0.92
PM_{10}	**0.93**	0.11	0.94
SO_2	0.05	**0.77**	0.39
NO	0.03	**0.81**	0.77
CO	**0.95**	0.06	0.96
NO_2	**0.88**	0.27	0.84
$PM_{2.5}$	**0.93**	-0.05	0.98
Asthma/Bronchitis'	-0.05	**0.58**	0.27
Tair_mean	**0.84**	-0.20	0.89
Expl.Var	4.97	1.72	
Prp.Totl	0.55	0.19	

Table 8. August 2005 factor extraction though the Principal Component Analysis. VARIMAX method of rotation.

4. Conclusions

Large scale meteorological phenomena such as ENSO and North Atlantic Oscillation (Rocha, 1999) can influence the precipitation in the Iberian Peninsula. This change has an impact on atmospheric dispersion of pollutants. Decreasing rainfall during the winter in a Mediterranean climate such as Porto, causes increased pollutant concentration and, as a consequence, reduced air quality.

The year 2005 was characterized by low rainfall, especially during the winter. The decrease in precipitation has created conditions for increasing the pollutants concentration. During the summer, high temperatures combined with forest fires decreased the air quality. Therefore, during the winter of 2005, the pollutants PM_{10}, $PM_{2.5}$, NO, CO and ozone were positively related to the respiratory diseases as well as air temperature and thermal comfort indexes are related negatively. During the summer of this particular year, pollutants like SO_2 and NO_2 were positively associated with respiratory diseases.

Good communication between service climate and weather forecasting and public health agencies can contribute to improve government healthcare policies to prevent an increase during those extreme natural phenomena.

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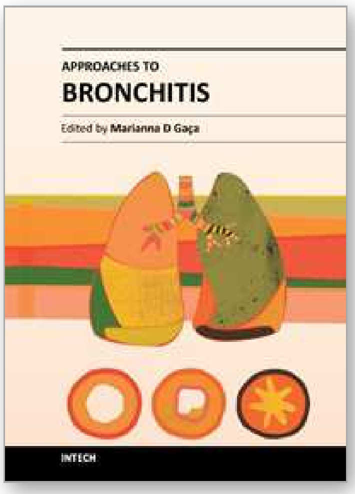

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The aim of this book is to present some recent and interesting findings in the field of bronchitis, which will serve as a supplement to the book Bronchitis. In particular, this volume focuses on the successful use and development of novel tools in the diagnostics and treatment of bronchitis. Contributions include clinical case studies, the impact of air pollution on bronchitis, the presentation and diagnosis of the respiratory disease eosinophilic bronchiolitis, primary ciliary dyskinesia, the development of a method for the swift detection of the infectious bronchitis virus and studies investigating the successful use of alternative medicines in the treatment of bronchitis. The editor would like to thank the authors of the chapters who have contributed to this book and hopes that this will book not only supplement the book on Bronchitis, but may increase interest in the subject.

How to reference

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821