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Urban ambient air pollution and daily mortality in Salamanca (Spain)

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Abstract

Several new studies published over the past decade have demonstrated a link between ambient air pollution and several adverse effects on human health even at the lower concentrations typically observed in North America and Europe today, suggesting that air pollution may pose a risk to public health. The effects on human health of gaseous air pollutants, such as ozone, nitrogen oxides, sulphur dioxide, and carbon monoxide, are not as well established.

Our study set out to determine the possible relations of variations in pollutants on mortality in the city of Salamanca (Spain), taking into account the possible confounding effect of other atmospheric variables. The study was based on daily mortality data (ICD-9 codes:390-459 cardiovascular ; 460-519 respiratory ; 520-579 digestive causes) from Spanish Institute of Statistics, and meteorological and air pollution data from the Municipal Automatic Air Pollution Monitoring, from 1995 to 1997.

Since we were interested in the acute effects of air pollution on mortality, the time series of daily counts of deaths were smoothed to remove trend, seasonal and sub-seasonal cycles. A minimum set of weather predictors (atmospheric variables and time lags) was selected using forward inclusion stepwise regression methods and these were used to produce a multivariate model of the different causes of mortality. A significant association was found among ozone, sulphur dioxide, mean temperature, relative humidity, solar radiation and mortality.

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1 Introduction

For several years interest in the effects of the weather on human health has occupied the limelight, especially since predictions concerning the possibility of global warming have come to the forefront of our attention. There is now clear evidence that specific meteorological situations such as air pollution or heat wave episodes have a severe impact on the daily activities of human beings and, indeed, the increase in mortality and morbidity observed in different human populations over the past few decades is the clearest indication of this relationship. Most studies carried out have pointed to the relationships between mortality or morbidity (mainly elicited by cardiovascular or respiratory problems) and episodes featuring high levels of atmospheric pollutants. Some of these studies carried out in North America [1], in China [2] or in Europe [3] have explored these relationships and have unveiled a predominant effect on mortality and morbidity and cardiovascular-related hospital admissions due to different atmospheric pollutants, such as particles in suspension, carbon monoxide (CO), nitrogen dioxide (NO_2) sulphur dioxide (SO_2) or ozone (O_3). In Spain, this type of analysis has been carried out for only a few years [4] and it does not seem appropriate to extrapolate the results from other parts of the world to the Spanish environment owing to Spain's particular meteorological and climatic characteristics, which are very different. Here we report a summary of the statistical characteristics of daily mortality produced by cardiovascular, respiratory and digestive causes and those of different atmospheric pollutants/variables in the city of Salamanca (Central-Western Spain) for the 1995-1997 period.

Using multiple linear regression methods, we also analysed the degree of association shown by the different time series studied and assessed the incidence of the atmospheric pollutants/variables on the number of deaths.

2 Methods

The city of Salamanca (40° 58' N, 5° 10' W) has a population of some 170,000 inhabitants and is situated in the NW zone of the Iberian Peninsula at a mean height of about 800 m.a.s.l. The climate in Salamanca is continental-temperate (12°C mean temperature), and features hot dry summers, with a mean temperature of more than 20°C, and cold winters, with means below 5°C .

Although Salamanca has no important industrial activity, its traffic density is considerable at certain times of the day, often leading to traffic problems that bring chaos to most of the inner part of the city.

The sources of pollution in the city mainly derive from automobile exhausts and the central heating systems of large buildings, which in many instances employ coal with a high concentration in sulphur compounds, which propitiates important emissions of SO_2 in winter [5]. To conduct the present work we used the data obtained from three automatic pollution-recording stations -all of them belonging to the Atmospheric Pollution Surveillance Network set up by the Municipal Corporation in conjunction with the Junta of Castilla y León

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(Regional Community in Spain)- over the past few years at certain particular sites in the city (Figure 1).

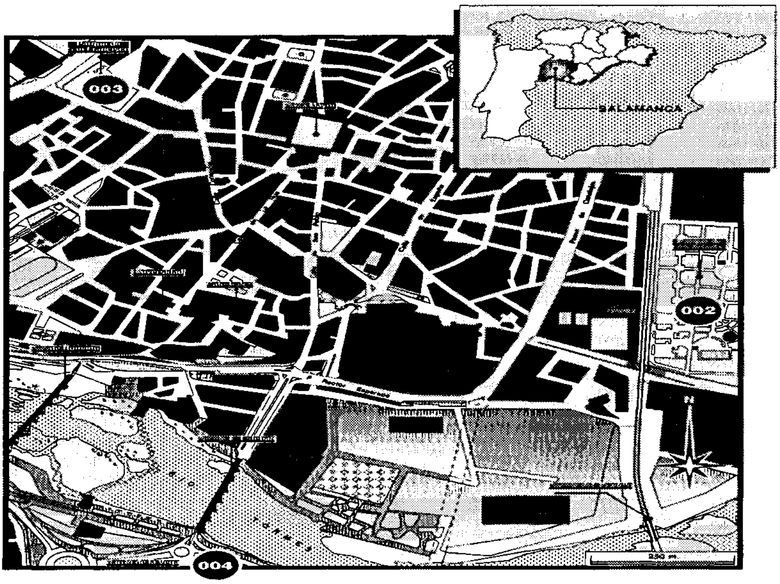

Figure1: Map of Salamanca city and location of the sampling stations.

The data on daily mortality were obtained from the National Institute of Statistics, together with identification of the causes of death, according to the codes of the International Classification of Diseases, 9th Revision, ICD-9; 390-459 cardiovascular diseases; 460-519 respiratory diseases and 520-579 digestive causes. The latter was selected as a control series since it would presumably show a weak interrelationship with atmospheric conditions.

Table 1 shows the pollutants and meteorological variables obtained from each of the stations, the period during which the data were collected, and the general characteristics of the location of each station. The pollutants and variables available were as follows: carbon monoxide (CO), nitrogen monoxide (NO) nitrogen dioxide (NO_2) ozone (O_3), sulphur dioxide (SO_2), wind direction (DIR), relative humidity (RH), atmospheric pressure (PRE), solar radiation (RAD), temperature (TEMP) and wind velocity (VEL).

3 Results and discussion

3.1 Descriptive statistics

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Table 2 (a), (b), (c) shows the mean values, standard deviations (SD), the maximum and minimum values, the skewness and kurtosis coefficients and the range of each of the variables measured for each station for the series of hourly means. As may be seen, the mean and maximum values of NO, NO_2 and O_3 varied significantly from one station to the next. The oxides of nitrogen (NO and NO_2) reached significantly higher concentrations at SA003 than at SA002 and SA004. By contrast, O_3 reached maximum mean values at SA004 (72.7 μg,m^{-3}) and minimum values at SA003 (41.7 μg.m^{-3}). The differences in the concentrations of NO, NO_2 and O_3 between the different stations are mainly due to their different locations.

Table 1: Selected time-series of air pollution and atmospheric variables.

	SA002	SA003	SA004
VAR/CONT	Hourly Average (%missing) Daily Average (%missing)	Hourly Average (%missing) Daily Average (%missing)	Hourly Average (% missing) Daily Average (% missing)
CO (mg·m^{-3})		1.1.96-31.7.96 (6.8 %)	21.1.96-31.7.96 (2.6 %)
		1.3.95-31.12.96 (2.4 %)	21.1.96-31.12.96 (2.6 %)
NO (μg·m^{-3})	1.1.95-31.7.96 (3.2 %)	1.1.96-31.7.96 (3.3 %)	21.1.96-31.7.96 (4.1 %)
	1.1.95-31.12.96 (1.8 %)	1.3.95-31.12.96 (2.0 %)	21.1.96-31.12.96 (2.6 %)
NO_2 (μg·m^{-3})	1.1.95-31.7.96 (3.4 %)	1.1.96-31.7.96 (3.3 %)	21.1.96-31.7.96 (4.5 %)
	1.1.95-31.12.96 (1.6 %)	1.3.95-31.12.96 (2.2 %)	21.1.96-31.12.96 (3.2 %)
SO_2 (μg·m^{-3})	1.1.95-31.7.96 (4.7 %)	1.1.96-31.7.96 (3.2 %)	21.1.96-31.7.96 (5.2 %)
	1.1.95-31.12.96 (3.4 %)	1.3.95-31.12.96 (1.2 %)	21.1.96-31.12.96 (2.0 %)
O_3 (μg·m^{-3})	1.1.95-31.7.96 (3.5 %)	1.1.96-31.7.96 (3.2 %)	21.1.96-31.7.96 (5.1 %)
	1.1.95-31.12.96 (2.4 %)	14.6.95-31.12.96 (1.2%)	21.1.96-31.12.96 (2.8 %)
DIR (° Hex)	1.1.95-31.7.96 (2.0 %)		
	1.1.95-31.12.96 (1.6 %)		
HR (%)	1.1.95-31.7.96 (3.0 %)		
	1.1.95-31.12.96 (2.7 %)		
PRE (h Pa)	1.1.95-31.7.96 (3.5 %)		
	1.1.95-31.12.96 (2.7 %)		
RAD (W·m^{-2})	1.1.95-31.7.96 (3.4 %)		
	1.1.95-31.12.96 (2.0 %)		
TEMP (° C)	1.1.95-31.7.96 (2.4 %)		
	1.1.95-31.12.96 (1.5 %)		
VEL (m.s^{-1})	1.1.95-31.7.96 (2.6 %)		
	1.1.95-31.12.96 (2.0 %)		
CARACT.	Placed at the entrance of a park and close to a motor vehicles traffic area.	Close to the intersection of two avenues with high traffic density.	Residential zone at the left margin of the river, placed on a parking area with a very low traffic density.

In this sense, SA003 is located on an avenue with a very high traffic density, thus accounting for the high concentrations of nitrogen oxides (86.5 μg,m^{-3} and 57.4μg,m^{-3} for the hourly series of NO and NO_2, respectively) and lower concentrations of O_3.

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Table 2. Descriptive statistics of pollutants and atmospheric variables.

(a) SA002

VAR/CONT	AVERAGE	S.D.	MAX.	MIN.	SKEWNESS	KURTOSIS	RANGE
NO ($\mu g \cdot m^{-3}$)	17.8	13.2	159.0	1.0	3.2	17.1	157.0
NO_2 ($\mu g \cdot m^{-3}$)	29.9	20.0	196.0	1.0	1.1	1.6	195.0
O_3 ($\mu g \cdot m^{-3}$)	56.2	25.7	218.0	3.0	0.7	0.5	215.0
SO_2 ($\mu g \cdot m^{-3}$)	25.5	23.2	243.0	1.0	2.4	8.0	242.0
DIR (H. Deg.)	128.2	79.4	348.0	0.0	-0.1	-0.7	348.0
RH (%)	70.7	21.3	99.0	15.0	-0.6	-0.7	84.0
PRES (hPa)	917.5	7.3	935.0	842.0	-0.9	1.4	93.0
RAD ($W \cdot m^{-2}$)	187.5	268.9	997.0	1.0	0.7	0.7	998.0
TEMP (°C)	13.7	7.1	37.0	-3.0	0.3	-0.3	40.0
VEL ($m \cdot s^{-1}$)	0.9	0.9	6.0	0.0	1.0	1.1	6.0

(b) SA003

CONT	AVERAGE	S.D.	MAX.	MIN.	SKEWNESS	KURTOSIS	RANGE
NO ($\mu g \cdot m^{-3}$)	86.5	87.7	826.0	4.0	2.1	7.8	822.0
NO_2 ($\mu g \cdot m^{-3}$)	57.4	34.0	241.0	3.0	0.4	-0.0	238.0
O_3 ($\mu g \cdot m^{-3}$)	41.7	17.1	116.0	8.0	0.6	0.3	108.0
SO_2 ($\mu g \cdot m^{-3}$)	39.0	25.4	251.0	5.0	2.0	5.8	246.0
CO ($mg \cdot m^{-3}$)	2.3	1.2	9.0	0.0	1.0	1.1	9.0

(c) SA004

CONT	AVERAGE	S.D.	MAX.	MIN.	SKEWNESS	KURTOSIS	RANGE
NO ($\mu g \cdot m^{-3}$)	22.7	55.5	1270.0	6.0	15.3	276.7	1264.0
NO_2 ($\mu g \cdot m^{-3}$)	29.7	18.3	298.0	2.0	2.9	24.6	296.0
O_3 ($\mu g \cdot m^{-3}$)	72.7	31.0	173.0	5.0	0.0	-0.1	168.0
SO_2 ($\mu g \cdot m^{-3}$)	13.9	11.0	95.0	1.0	2.6	9.9	94.0
CO ($mg \cdot m^{-3}$)	1.0	0.3	4.0	0.0	0.4	6.3	4.0

SA002 is located in a zone close to a street where the traffic density is not important. However, the presence of one of the largest parks in the city close by could exert some complementary effect. Finally, SA004 is located in a residential zone close to a street with a low traffic density.

The trends of sulphur dioxide (SO_2) and of carbon monoxide (CO) are similar to those reported above for the nitrogen oxides. SA003 was the station at which the highest mean values were recorded for both these gases, again pointing to the pronounced effect of human activities on pollutant concentrations, even in medium-sized cities with little industry.

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The high variability of the hourly values of NO, especially at SA003 and SA004, can be attributed to emissions coming from the traffic. At SA004, this variability is particularly marked. The asymmetry (skewness) and sharp (kurtosis) coefficients reflect a distribution close to normal or Gaussian for both the meteorological variables and O_3. The rest of the pollutants show higher skewness and kurtosis values, above all those corresponding to NO and SO_2, at all three stations, those from SA004 being outstanding.
Table 3 offers a summary of the basic characteristics of daily mortality for each of the causes of death differentiated by sex. It may be seen that cardiovascular diseases have an incidence four-fold higher than diseases of the respiratory system and 8-fold higher than deaths due to digestive causes (4.0:1.0:0.5).

Table 3. Summary of the daily number of mortality for cardiovascular, respiratory and digestive causes. (Number of days of valid observations= 1095)

CAUSE OF DEATH	MEAN	S.D.	MAX.	MIN.	SKEWNESS	KURTOSIS
CARDIVASCULAR DISEASES						
TOTAL	4.0	2.1	11	0	0.49	0.05
MALES	1.8	1.4	10	0	0.93	1.42
FEMALES	2.2	1.5	8	0	0.70	0.46
RESPIRATORY DISEASES						
TOTAL	1.0	1.0	5	0	1.03	0.76
MALES	0.6	0.8	5	0	1.24	1.43
FEMALES	0.4	0.6	4	0	1.82	3.65
DIGESTIVE DISEASES						
TOTAL	0.5	0.7	4	0	1.40	1.79
MALES	0.3	0.5	3	0	1.86	3.06
FEMALES	0.2	0.4	4	0	2.50	8.19

Additionally, the proportion of cardiovascular disease-due deaths in male/female was 0.82 as compared with 1.5 for respiratory- and digestive -due deaths, this being one of the differentiating characteristics among the three causes of death.
The proportion between the daily maxima of deaths (male/female) is similar for both the cardiovascular and respiratory causes (1.25) and different for digestive causes (0.75). Regarding the values of the standard deviations, it may be deduced that the mortality due to respiratory and digestive causes have similar values to their respective means, suggesting for this series an overdispersion due to non-random or deterministic causes, this being characteristic of series showing a Poisson distribution. By contrast, the mortality due to cardiovascular causes does not show this feature of overdispersion and has a mean value different from its standard deviation.

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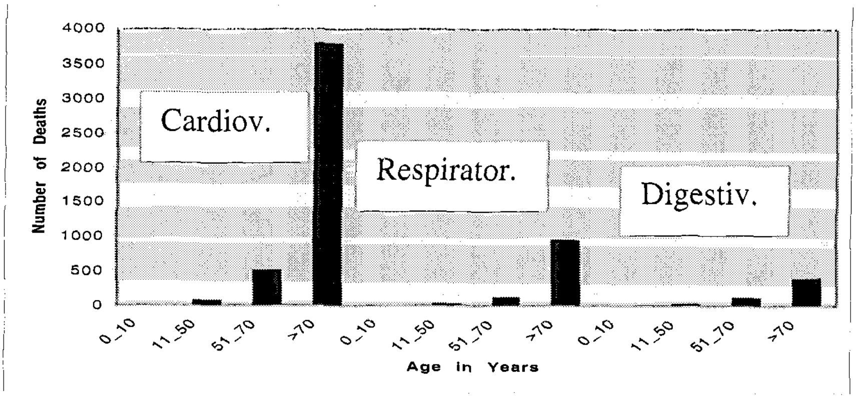

Figure2. Distribution of daily mortality by age group in cardiovascular, respiratory and digestive causes.

Figure2 shows the frequency distribution of cumulative daily mortality classified by age groups and for each cause of death analysed. The population older than 70 shows a clear incidence in death due to cardiovascular disease, which is lower in the cause of respiratory causes and negligible (not very representative) for digestive causes. The other age group with a high mortality incidence due to all three causes included people of between 51 and 70 years of age, although in the digestive causes (control group) the differences among the different age groups was not very significant.

3.2. Annual evolution.

Figure 3 shows the evolution of the mean daily values of the different pollutants and the meteorological variables of each surveillance station.
O_3 reached higher mean daily values during the summer months and lower values during winter. This kind of behaviour is due to the higher amount of solar radiation reaching the surface during the summer, thereby favouring the photochemical creation of O_3. In the case of NO and NO_2, it is difficult to discern any characteristic annual pattern. By contrast, SO_2 did show a cyclic behaviour along the period studied, higher mean values being attained in the winter months. This can be explained in terms of the notion that during these months (winter) the central heating systems of large buildings are in operation, these being the main source of SO_2. CO did not follow any particular annual pattern attributable to any given phenomenon either. However, there was a slight tendency for the mean daily values recorded at SA003 to increase, although a longer period would be necessary to confirm this. The mean daily values of temperature and radiation followed a normal type of behaviour for both variables. Regarding wind speed, no special cycles was observed as regards mean daily values.

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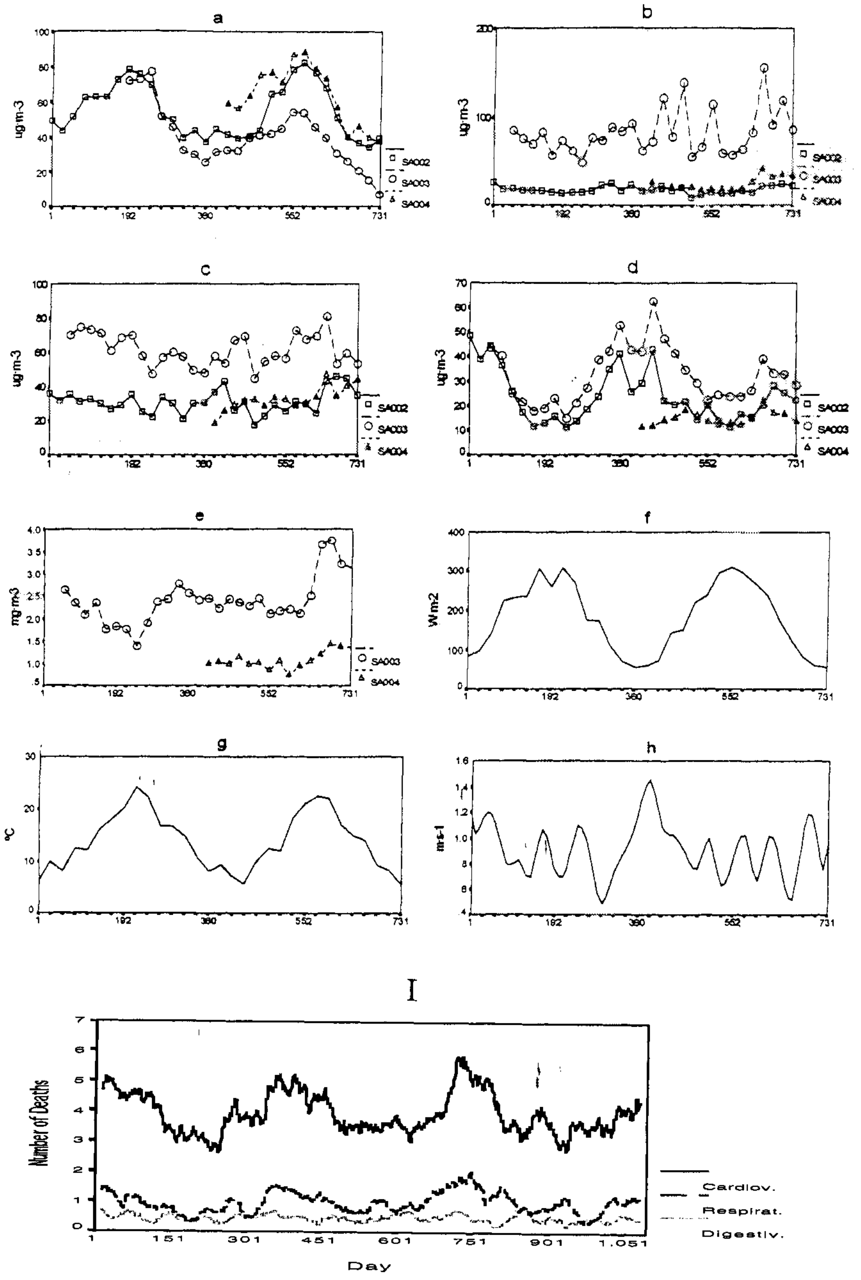

Figure 3. Mean daily evolution during the studied time period of O_3 (a), NO (b), NO_2 (c), SO_2 (d), CO (e), solar radiation (f), temperature (g)wind speed (h), and mortality(I).

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3.3. Multivariate analysis.

Different statistical models can be used to analyse the association between daily mortality and weather/air pollution. Most such methods use linear regression models, non-linear regressions on the smoothed variable or variations of the Poisson model, also considering different combinations between the meteorological and pollutant data.

Here we used a multiple linear regression analysis with a view to determining the variables that show the strongest relationship with daily mortality. Both the mortality series and those of the pollutants and atmospheric variables show cycles of long-term and short-term periods that must previously be filtered for correct application of the model. To do so, we previously performed a non-parametric smoothing of our data (a generalisation of a weighted moving average), resulting in a filtered final series that could be interpreted as smoothed measures of daily mortality, weather effects and pollution levels.

Table 4 shows the correlation coefficients obtained among all the variables. It is possible to appreciate the high coefficient between mortality due to cardiovascular causes and temperature, with a negative correlation and SO_2 among the pollutants. Emphasis should be placed on the co-linearity between temperature and, mainly, the levels of O_3 and SO_2. Also, in the case of mortality due to digestive causes, temperature and radiation show high values, O_3 being the pollutant with the greatest incidence, followed by SO_2. In the case of mortality due to digestive causes, the correlation coefficients obtained are clearly lower than those seen for the other causes, radiation, relative humidity and SO_2 being those with the greatest incidence. We also analysed the different variables and pollutants with lags of 1,2,3,4 and 5 days, but failed to obtain significant values in any case. Finally, we implemented different linear models and a summary of the best ones tested is shown in Table 5. It seems clear that the models without any transformation afford the best results (they explain 57% and 55% of the variance of the series) and the application of logarithms to the mortality series due to respiratory or digestive causes, to obtain Poisson distributions, did not give better results than the original smoothed series.

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Table 4. Correlation matrix (zero lag) of smoothing series.

	Mortality			Weather					Pollutants			
	C	R	D	Tem	RH	Rad	Pres	Vel	SO_2	O_3	NO	NO_2
C	1.00	0.65	0.20	**-0.71**	0.55	-0.62	-0.41	0.38	**0.65**	-0.54	0.40	0.35
R		1.00	0.33	**-0.65**	0.61	**-0.63**	-0.46	0.39	0.51	-0.58	0.43	0.46
D			1.00	-0.28	**0.28**	**-0.30**	-0.14	0.18	**0.28**	-0.19	0.27	0.15
Tem				1.00	-0.83	0.83	0.53	-0.33	-0.81	0.83	-0.51	-0.39
RH					1.00	-0.90	-0.61	0.34	0.57	-0.85	0.45	0.30
Rad						1.00	0.47	-0.33	-0.67	0.89	-0.61	-0.39
Pres							1.00	-0.45	-0.17	0.43	-0.01	-0.40
Vel								1.00	0.29	-0.11	-0.12	-0.07
SO_2									1.00	-0.60	0.52	0.38
O_3										1.00	-0.67	-0.45
NO											1.00	0.72
NO_2												1.00

Table 5. Summary of parameter estimates from ordinary least squares regressions.

DEPEND.	INDEPENDENT										
	(B) Regression Coefficient										R-Sq
	Const.	Tem	RH	Rad	Pres	Vel	SO_2	O_3	NO	NO_2	
Cardiovasc.	23.80	-0.066	-0.016	-0.003	-0.020	0.316	0.012	0.009		0.011	**0.57**
Respirator.	8.65	-0.016		-0.001	-0.009	0.300				0.014	**0.55**
Digestiv.	-0.407	-0.008	0.005	-0.001				0.009	0.015	-0.002	**0.21**
Respirat. (log)	-0.082	-0.011				0.155		-0.002		0.005	**0.46**
Digestiv. (log)	-1.064	-0.006	0.004	-0.001				0.008	0.009		**0.18**