Atmósfera 19(1), 23-39 (2006)

Relationships of daily mortality and hospital admissions to air pollution in Castilla-León, Spain

F. DE PABLO, A. LÓPEZ, L. RIVAS SORIANO, C. TOMÁS
Facultad de Ciencias, Universidad de Salamanca, España
Corresponding author: F. de Pablo; e-mail: fpd123@usal.es

L. DIEGO, M. GONZÁLEZ,
Instituto Regional de Salud Pública, SACYL Castilla-León, España

M. BARRUECO
Facultad de Medicina, Universidad de Salamanca, España

Received September 25, 2003; accepted October 25, 2005

RESUMEN

Se analizan las posibles relaciones existentes entre la mortalidad de la población, el número de admisiones hospitalarias (morbilidad) y los niveles de concentración de contaminantes medidos en siete localidades y cuatro hospitales de Castilla-León, España, respectivamente, teniendo en cuenta el posible efecto de enmascaramiento que ejercen las variables atmosféricas. El estudio se basa en datos diarios (1995-1997) de mortalidad y admisiones hospitalarias según el Código Internacional de Enfermedades (ICD-9: 390-459 causas cardiovasculares; 460-519 respiratorias; 520-579 digestivas); además, utilizamos datos de variables meteorológicas (temperatura del aire, humedad relativa, radiación solar, presión atmosférica y velocidad de viento) así como valores de contaminantes gaseosos (SO_2, O_3, NO, NO_2 y CO) de los distintos lugares. Mediante el método de regresión lineal múltiple y la selección paso a paso de las diferentes variables utilizadas, se determinó el número óptimo de predictores a seleccionar, que fueron posteriormente utilizados para generar un modelo multivariado respecto de la mortalidad y la morbilidad. La mortalidad atribuible a causas cardiovasculares es mayor que la atribuida a causas respiratorias y las de origen digestivo. Las distribuciones de frecuencias correspondientes a cada tipo de enfermedad clasificadas por intervalos de edad, indican que la población mayor de 69 años es la más afectada por estas enfermedades, obteniéndose además que las causas de origen cardiovascular para este grupo de edad presentan una incidencia 7 veces más alta que las debidas a las de origen respiratorio o digestivo. La mortalidad y la morbilidad debidas a causas respiratorias y cardiovasculares presentan un alto coeficiente de correlación con las variables temperatura, radiación solar y con el contaminante ozono, mostrando correlaciones ligeramente inferiores con el SO_2.

ABSTRACT

We examined the possible relationships between pollutant concentrations and mortality at seven different locations of Castilla-León, Spain, and the relationships between such concentration levels and emergency admissions (morbidity) at four hospitals in the region, taking into account the possible masking effect of other atmospheric variables. The study was based on daily mortality and morbidity data from 1995 to 1997 (ICD-9 codes: 390-459 cardiovascular; 460-519 respiratory; 520-579 digestive causes); moreover, data for meteorological variables (air temperature, relative humidity, solar radiation, atmospheric pressure and wind velocity) and air pollution data (SO_2, O_3, NO, NO_2 and CO) were used. A minimum set of weather and pollutant predictors was selected using forward inclusion stepwise linear regression methods and these were used to produce a multivariate model of the different causes of mortality and morbidity. For the whole period, the mortality attributable to cardiovascular causes had an incidence higher than the mortality due to respiratory and digestive causes. The frequency distributions corresponding to the different diseases as classified by ages revealed that the population older than 69 is the most affected, the proportion of cardiovascular disease-related deaths in this age sector being 7-fold higher than for the rest of the groups. Mortality and morbidity due to respiratory and cardiovascular-related diseases showed a high correlation coefficient with temperature, solar radiation and ozone, and in general significant correlations were also seen with SO_2.

Key words: Mortality and morbidity, pollutants and meteorological variables, multiple linear regression analysis, Spain.

1. Introduction

Since the time of Hippocrates, medical professionals have spent much time studying the effects of atmospheric variations on human health, although such efforts were shared by specialists in other areas only until the end of the twentieth century. Above all, in the past fifteen years the interest of physicians in the impact of the weather on the health of living beings has been shared by researchers originally trained in other disciplines, mainly meteorology and climatology.

In recent years, apart from the influence of adverse atmospheric variations in the daily lives of human beings, episodes of high concentrations of atmospheric pollutants have also led to an increase in mortality and in the number of emergency hospital admissions. Thus, the spectacular increase in mortality during the events that occurred in the Meuse Valley in Belgium in 1930 (Firket,1931) in Donora in 1948 (Shrenk *et al*., 1949), and in London, in 1952 (HMSO,1954) –where there were more than 4000 deaths due to the high levels of pollution– indicates the direct relationship that must exist between health and atmospheric pollution. This has meant that epidemiological studies on health and its relationship with weather or climate have focused on the analysis of both individual meteorological variables and the concentrations of different gaseous pollutants. Some of these studies carried out in Australia (Guest *et al*.,1999), Brasil (Saldiva *et al*.,1995), Greece (Toulomi *et al*.,1996), Italy (Michelozzi *et al*.,1998), North America (Fairley, 1990; Pope III *et al*.,1992; Schwartz and Dockery 1992; Schwartz 1994; Calderón *et al*., 1997; Smith *et al*., 2000; Smoyer *et al*., 2000), South America (Ostro *et al*., 1996; 1997) and in the United Kingdom (McGregor *et al*., 1999) have explored such relationships and have reported the predominant effect on mortality and hospital admissions –mainly of cardiovascular or respiratory origin– exerted by atmospheric pollutants such as particles in suspension, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide

(SO_2) or ozone (O_3). In Spain, this type of analysis has only been carried out for a few years (Saez *et al*., 1995, 1999; Sunyer *et al*., 1996, Alberdi *et al*., 1998; Ballester *et al*., 2001; Díaz *et al*., 2001; González *et al*., 2001), and it does not appear to be appropriate to extrapolate the results from other parts of the world to our area owing to the diversity of our meteorological and climatic characteristics.

We aimed to produce a description of mortality/hospitalization and of meteorological and pollutants variables, and to determine which atmospheric variables and pollutants show the strongest relationship with daily mortality/morbidity.

Here we offer a summary of the statistical characteristics of daily mortality and morbidity produced by cardiovascular, respiratory and digestive causes, together with the characteristics of the different meteorological and pollutants variables measured synchronously in the Regional Community of Castilla-León (north-west Spain) during the 1995-1997 period.

2. Methods

2.1 *Study area*

Castilla-León is situated in the NW of Iberian Peninsula (Fig.1) and has a surface area of 93,147 km^2; i.e., about one fifth of Peninsular Spain. It has a relatively high mean altitude (700 m a.s.l.) and is isolated by its orography. Except in the west, Castilla-León is surrounded by large mountain systems, which act as barriers to the maritime influence, affording the region a continental climate with long cold winters (mean temperature below 5°C in January) and hot dry summers (mean temperature 20°C in July) (Font, 1983). Owing to this orographic isolation, in most of the region annual mean precipitation is not very high, ranging between 400 and 900 mm in mountainous zones. The most frequent winds (disregarding the effect of relief) come from the W, SW, NW, N and NE (García and Reija,1994). The study zone has a population of 2.5 million; i.e., 6.6% of the population of Spain. The region contains no large urban centers and Valladolid is by far the largest city in the region. With the exception of this city, industrial activity in the region is not very intense, at least in comparison with other regions in the country. The main sources of the emission of atmospheric pollutants in the region are vehicles, central heating systems and, to a lesser extent, industry.

2.2 *Data*

2.2.1 *Study population*

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 group was selected as a control series since it would presumably show a weak interrelationship with atmospheric conditions.

The number of daily hospital admissions (morbidity) was obtained from the registry databases of four hospitals: Nuestra Señora de Sonsoles (Ávila), General Yagüe (Burgos), Virgen del Camino (León) and the Hospital Universitario (Salamanca), with a catchment area of nearly 800,000 inhabitants, and were selected with a primary discharge diagnosis of similar mortality causes: cardiovascular, respiratory and digestive diseases.

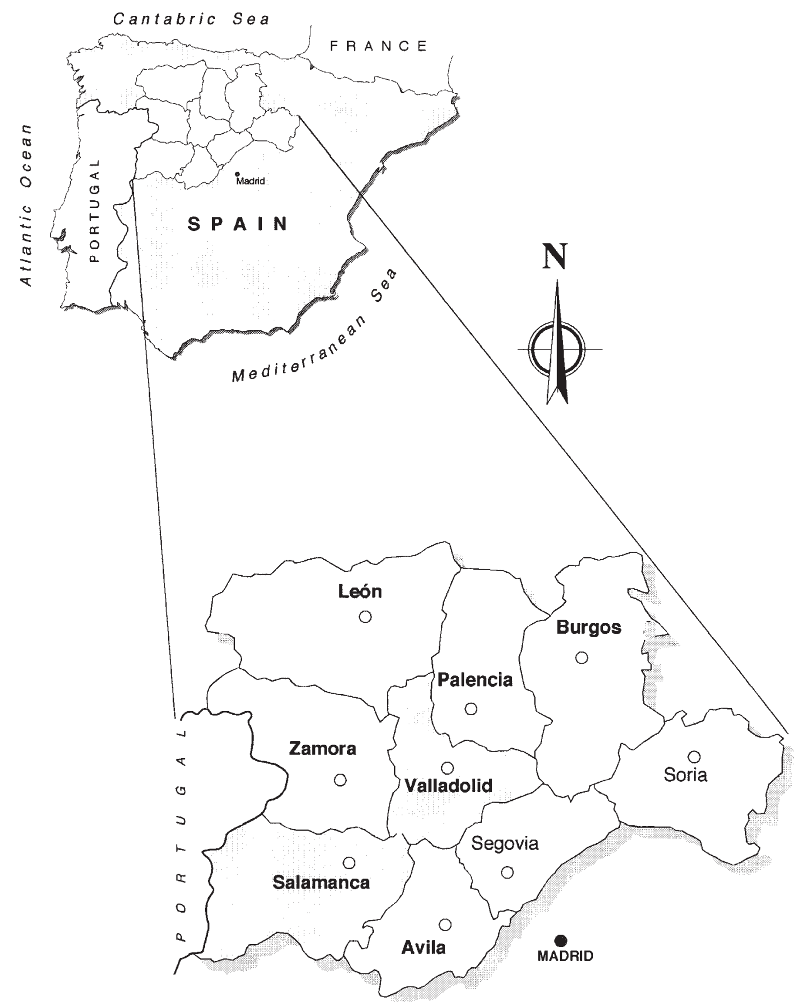

Fig. 1. Location of Castilla-León on the Iberian Peninsula, showing the provinces (in bold-faced type) where stations and hospitals are located.

With a view to analyze the data on the mortality and morbidity of the different populations jointly, we previously carried out standardization, referring to deaths per 100,000 inhabitants, according to the population census corresponding to January 1, 1998. To do so, we used the concept known as ‘‘standard population’’ proposed by Kalkstein and Davis (1989), in which first the average of the total population of the region analyzed is determined and then the absolute mortality values of each site are corrected by the values obtained for the ‘‘standard population’’. Henceforth, the data on mortality and morbidity used will be referred to the standard population, which should permit direct comparisons of the results obtained with different populations.

2.2.2 Exposure data

Castilla-León has a network of atmospheric pollution control stations comprising 38 automated stations distributed throughout urban centers and adjacent zones; in the present study, seven of them were used as data sources. The location and the basic characteristics of the observation stations are shown in Table 1. In this table, ‘‘intense traffic’’ means that in the neighborhood of the monitoring station there is a main street characterized by the large number of motor vehicles circulating along it. This situation often leads to persistent traffic jams during most of the day, especially on weekdays. ‘‘Very light traffic’’ means that motor vehicles occasionally circulate in the neighborhood of the monitoring station; i.e., the effect of traffic emissions in the area is negligible. ‘‘Light’’ (a low number of motor vehicles circulating in the area) and ‘‘moderate’’ (intermittent circulation of motor vehicles but with no traffic jams) refer to two intermediate situations between very light and intense traffic.

Table 1. Sites and basic characteristics of locations. (ID, station-identifying code. Altitude in meters; h. i., heavy industry (metallurgy, chemical, power station, etc.).

Site characteristics						Monitoring station site		
City	ID	Population	Lat. N	Lon. W	Altitude	Zone	Type	Traffic
Ávila	AV	167,132	43° 33′	4° 42′	1131	Urban	Residential	Light
Burgos	BU	346,355	42° 20′	3° 13′	929	Rural	Agricultural	Very light
León	LE	506,365	42° 39′	5° 1′	838	Urban	Residential	Intense
Palencia	PA	179,623	42° 1′	4° 3′	739	Urban	Residential	Light
Salamanca	SA	349,550	40° 58′	5° 10′	797	Urban	Residential	Moderate
Valladolid	VA	492,029	41° 38′	4° 43′	685	Suburban	h. i.	Very light
Zamora	ZA	205,201	41° 30′	5° 45′	649	Urban	Residential	Moderate

Previous studies (Panero *et al*.,1997; Alvarez *et al*., 2000) analyzed the characteristics and the spatial-temporal variability of atmospheric pollutants (SO_2, O_3, NO, NO_2 and CO) in the region and the relationship between these contaminants and certain meteorological variables: temperature (T), relative humidity (RH), solar radiation (SR), atmospheric pressure (P) and wind velocity (WV). Automatic analytical techniques were used to measure pollutant concentrations and variables, which were tested and calibrated monthly, taking samples every half or quarter of an hour. The hourly average concentration was obtained as the mean of the concentrations obtained in each sub-period and the data used here correspond to the recordings of average daily values from January 1, 1995 to December 31, 1997. Table 2 shows the air pollutants and meteorological variables measured at each of the stations, as well as some statistical parameters of the time-series analyzed.

Table 2. Descriptive statistics of daily average concentrations of air pollutants and atmospheric variables. Mean average and standard deviations in parenthesis.

Station	CO[a]	NO[b]	NO_2[b]	O_3[b]	SO_2[b]	T[c]	RH[d]	P[e]	SR[f]	WV[g]
AV	1.2	27.8	41.4	62.6	15.6	9.5	58.1	866	200.5	1.0
	(1.0)	(37.5)	(29.2)	(28.7)	(13.6)	(7.9)	(28.9)	(13.9)	(266.9)	(0.9)
BU				67.2	24.7	11.7	65.6	910	250.5	2.3
				(31.2)	(21.4)	(6.1)	(17.0)	(7.2)	(254.9)	(1.4)
LE	1.7	49.0	56.5	54.8	45.4	12.6	73.4	862	192.0	0.6
	(1.7)	(41.7)	(24.2)	(30.6)	(38.5)	(7.1)	(19.7)	(3.4)	(229.1)	(0.7)
PA	1.6	48.3	53.5	66.0	20.6					
	(1.0)	(41.0)	(32.6)	(32.5)	(17.9)					
SA		24.3	35.6	53.4	23.9	13.9	70.1	922	192.9	0.9
		(49.8)	(27.3)	(28.0)	(19.7)	(6.8)	(21.5)	(12.9)	(259.8)	(0.9)
VA		8.9	13.2	53.6	8.9	13.3	65.0	945	242.2	2.7
		(15.8)	(13.5)	(38.8)	(10.8)	(8.1)	(21.8)	(27.6)	(156.4)	(1.9)
ZA	1.3	29.3	42.4	46.4	15.8	14.2	68.9	938	203.3	0.5
	(0.8)	(30.1)	(24.5)	(25.5)	(8.2)	(7.2)	(18.7)	(7.2)	(243.6)	(0.4)

(Units: a (mg/m^3), b (µg/m^3), c (°C), d (%), e (hPa), f (W/m^2), g (m/s)).

2.3. Analysis

There are different statistical models available for analyzing the association between daily mortality or morbidity, and atmospheric pollutants and meteorological variables. Most of them (Shumway *et al*.,1988; Schwartz,1993; Yuanzhang and Roth, 1995) use linear regression models, non-linear regressions on the smoothed variable, or variations to the Poisson model. Different combinations between the meteorological data and atmospheric pollutants are also considered. Unfortunately, the results generated by the models differ and there is no sound justification for the use of one model over another.

Here we carried out a multiple linear regression analysis with a view to determining which atmospheric variables and pollutants show the strongest relationship with daily mortality or morbidity. The method used was stepwise least squares, which allows one to analyze the contribution of each independent variable in each of the steps, thus selecting the variables that explain the greatest variance of the dependent variable and ruling out those that do not make a significant contribution. Both the mortality and morbidity series and that of the atmospheric and pollutants variables show cycles that must previously be filtered for correct application of the model. To do so, we previously performed a non-parametric smoothing of the data, thereby obtaining filtered series that can be interpreted as smoothed measurements of daily mortality and morbidity, atmospheric pollution and the meteorological variables. The method of smoothing the daily weather data and daily mortality or hospital admissions is locally-weighted regression and smoothing scatterplots, a generalization of a weighted moving average. The smoother is characterized by defining a window of observations with fixed length about a specified day (Burnet *et al.*,1998).

3. Results

Table 2 shows the mean values and their respective standard deviations corresponding to the pollutants and atmospheric variables recorded at each of the seven observation stations analyzed. It may be seen that the station in León, where the traffic is classified as ‘‘intense’’ (Table 1), records the highest mean values for CO, NO and NO_2. The lowest mean values for the concentrations of these pollutants correspond to stations in whose neighborhood the traffic is classified as ‘‘light’’ or ‘‘very light’’. Naturally, this is because the source of such pollutants is the use of fossil fuels, mainly from motor vehicles, the central heating systems of large buildings, and industry (Seoánez, 1996).

Ozone has mean values ranging between 46.4 $\mu g/m^{-3}$ in Zamora and 67.2 $\mu g/m^{-3}$ in Burgos. In general, the lowest mean values are seen at stations in which the mean NO_2 concentration is much higher than the mean concentration of NO. The correlation coefficient between the daily mean O_3 and NO values, considering jointly all the analyzed stations and eliminating the effect caused on both by the other pollutants, is $r = -0.65$; whereas the partial correlation coefficient, obtained in a similar way, between the daily mean concentrations of O_3 and NO_2, is 0.42. In general, it was found that at the stations in which the ratio between NO_2 and NO concentrations was high, there were higher O_3 concentrations than at those in which the ratio was low. This can be explained in terms of the photochemistry of O_3. NO_2 favors the formation of O_3 in the presence of CO, volatile organic compounds (VOC) and solar radiation, whereas NO favors ozone destruction, this latter process also being faster (McKendry, 1993; Pryor and Steyn, 1995). Accordingly, urban zones in which traffic is more intense tend to acts as O_3 sinks, while in rural and suburban areas higher concentrations are reached.

Table 3 shows the descriptive statistics of mortality corresponding to each site analyzed. From this, it may be deduced that the mortality attributable to cardiovascular causes is between 3-fold (Burgos, León and Palencia) to 4-fold (Ávila, Salamanca, Valladolid and Zamora) greater than the mortality due to respiratory causes and between 5-fold (Valladolid) and 9-fold (Ávila) greater than that of digestive origin. Additionally, the proportion of cardiovascular-related deaths in males and females is in general lower than deaths caused by respiratory and digestive affections.

Table 3. Summary of daily number of deaths due to cardiovascular, respiratory and digestive causes (number of days of valid observations = 1095. Mean average. SD: standard deviation. Max: maximum absolute of deaths).

Cause of death	Ávila			Burgos			León			Palencia		
	Mean	S. D.	Max.	Mean	S. D.	Max.	Mean	S. D.	Max	Mean	S. D.	Max.
Cardiovascular												
Total	3.5	2.3	15.3	2.3	1.3	7.4	2.3	1.0	5.7	2.9	2.0	9.0
Males	1.6	1.6	9.6	1.2	0.9	5.6	1.2	0.7	3.8	1.3	1.4	7.2
Females	1.8	1.5	7.7	1.1	0.8	4.6	1.2	0.6	3.2	1.5	1.4	5.4
Respiratory												
Total	0.9	1.3	7.7	0.8	0.9	4.6	0.8	0.7	3.8	0.9	1.2	5.4
Males	0.6	1.0	5.8	0.4	0.7	3.7	0.5	0.6	2.5	0.5	1.0	5.4
Females	0.3	0.7	5.8	0.3	0.5	2.8	0.3	0.4	1.9	0.3	0.7	3.6
Digestive												
Total	0.4	0.9	3.9	0.4	0.6	2.8	0.4	0.5	2.5	0.5	0.9	5.4
Males	0.2	0.7	3.9	0.2	0.4	2.8	0.2	0.4	2.5	0.3	0.7	3.6
Females	0.2	0.6	3.9	0.1	0.4	1.9	0.2	0.3	1.3	0.2	0.6	5.4

Cause of death	Salamanca			Valladolid			Zamora		
	Mean	S. D.	Max.	Mean	S. D.	Max	Mean	S. D.	Mean
Cardiovascular									
Total	2.8	1.33	7.3	2.1	1.0	5.2	3.3	2.0	12.5
Males	1.4	1.0	4.6	1.0	0.7	3.3	1.5	1.4	7.8
Females	1.5	0.9	4.6	1.1	0.6	3.3	1.7	1.3	7.8
Respiratory									
Total	0.8	0.9	3.7	0.6	0.6	3.3	0.9	1.2	6.3
Males	0.5	0.7	2.8	0.4	0.5	2.6	0.5	0.9	4.7
Females	0.3	0.5	3.8	0.2	0.4	1.3	0.4	0.8	4.7
Digestive									
Total	0.4	0.6	2.8	0.4	0.5	2.6	0.4	0.8	4.7
Males	0.2	0.5	2.8	0.2	0.4	2.0	0.2	0.6	4.7
Females	0.2	0.4	2.8	1.1	0.6	3.3	0.2	0.5	4.7

The proportion of daily maxima in mortality by sex (male/female) varies for each province and for each cause of disease. Thus, for example, in Salamanca, Valladolid, Zamora and León the proportion is close to or equal to one for cardiovascular and digestive diseases, whereas in the case of respiratory-related mortality this proportion is seen in Ávila and Zamora. Palencia, Ávila and Burgos have male/female ratios of 1.33, 1.25 and 1.22, respectively, in the maximum mortality values due to cardiovascular causes. Regarding the results on standard deviation, it may be inferred that mortality due to respiratory and digestive causes has values similar to or greater than the respective mean values, suggesting –for this series– an overdispersion due to non-random factors, this being characteristic of data showing Poisson distributions (Schwartz, 1993; Burnett *et al*.,1998). By contrast, mortality due to cardiovascular causes does not show the characteristic of over-dispersion, the mean value in each case being higher than its standard deviation.

The frequency distributions of accumulated daily mortality, corresponding to the different diseases classified by ages (Fig. 2), show that the population older than 69 is the most affected and the proportion of cardiovascular-related deaths in this age sector is 7-fold higher than for the rest of the groups. In deaths due to respiratory or digestive causes, the proportion between the different age groups is appreciably lower, being almost zero for the age group between 0 and 10 years in all causes of death. These characteristics are similar to those reported in better-developed countries and hence ensuing analyses were performed, using multiple linear regression without differentiating among the age groups.

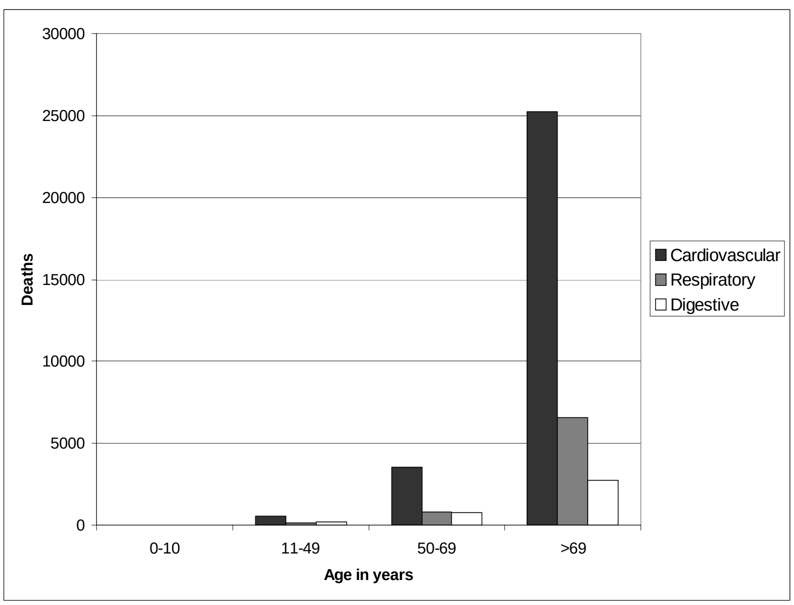

Fig. 2. Distribution of accumulated daily mortality by age group in cardiovascular, respiratory and digestive diseases. (The data used be referred to "standard population" proposed by Kalkstein and Davis, 1989).

A summary of the basic characteristics of morbidity recorded at the four hospitals considered is shown in Table 4. From this table it may be deduced that the mean daily number of hospital admissions can be characterized first by the cardiovascular-type diseases (an average of 6.7 cases/day), followed by digestive diseases (5.8 cases/day), with the exception of the hospital in Salamanca, where there is a predominance of admissions for digestive reasons, followed by cardiovascular-related diseases. In all cases, admissions due to diseases of respiratory origin are lower (between 0.6 and 0.8) than dominant causes. The maximum daily incidence corresponds to cardiovascular causes in the hospitals in Ávila and León; those of respiratory origin in Burgos, and those of digestive type in Salamanca. The male/female ratio for all types of disease selected is in favor of men, with a ratio of 1.6 for cardiovascular and respiratory admissions, and 1.3 for those of digestive origin. The asymmetry and sharpness coefficients for the three classes of disease indicate that the frequency distributions are normal or Gaussian for a significance level of $p > 0.005$.

Table 4. As in Table 3, for hospital admissions (morbidity).

	Ávila			Burgos			León			Salamanca		
Disease group	Mean	S. D.	Max.	Mean	S. D.	Max.	Mean	S. D.	Max.	Mean	S. D.	Max
Cardiovascular												
Total	9.1	4.5	25.0	6.3	3.3	17.6	4.8	2.8	14.5	7.1	2.9	18.4
Males	5.7	3.4	19.2	4.0	2.4	13.9	3.0	2.0	10.1	4.0	2.1	11.0
Females	3.4	2.6	13.4	2.3	1.7	10.2	1.8	1.3	6.3	3.0	1.8	10.1
Respiratory												
Total	6.9	4.6	25.0	5.3	3.5	24.1	2.9	1.9	10.1	5.5	2.9	15.6
Males	4.4	3.4	19.2	3.3	2.4	15.8	1.8	1.3	8.2	3.5	2.2	12.9
Females	2.4	2.5	13.4	2.1	1.7	9.3	1.1	1.0	6.3	2.0	1.5	10.1
Digestive												
Total	7.9	4.3	21.1	5.5	3.0	16.7	4.1	2.4	12.0	8.9	3.9	22.0
Males	4.6	3.2	17.3	3.2	2.1	11.1	2.4	1.6	8.8	5.3	2.8	16.5
Females	3.3	2.6	13.4	2.3	1.7	8.3	1.7	1.2	6.3	3.6	2.1	13.8

Regarding the incidence of the different causes of morbidity analyzed and their distribution by age (Fig. 3), the number of admissions is not limited mainly to the over 69 age group, as happened with the data on mortality; instead the other age groups show significant incidences.

Whereas admissions of cardiovascular origin decrease rapidly as the age of the patients decreases, digestive diseases remain constant in the adult age groups, decreasing in the 0-10 age group and the admissions due to respiratory-type affections show a lower incidence than the other two, showing a similar distribution for all the groups, whatever their age.

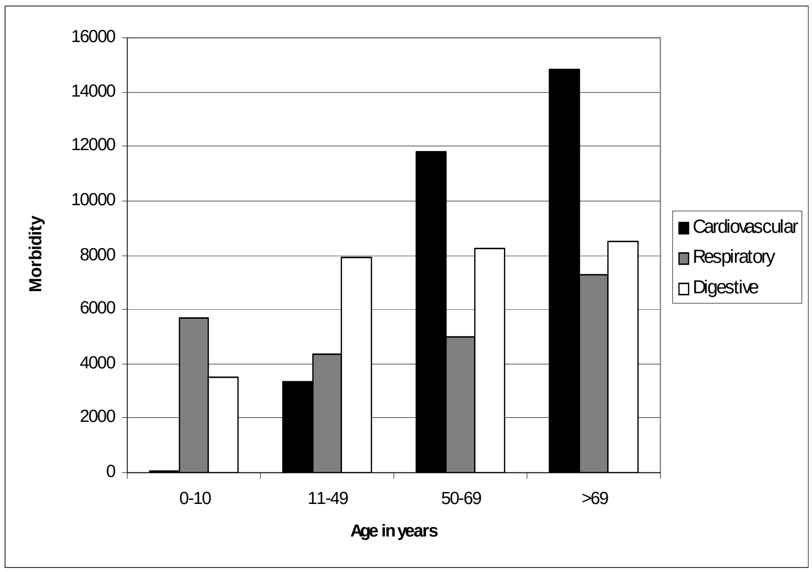

Fig. 3. Distribution of accumulated daily morbidity by age group in cardio-vascular, respiratory and digestive diseases. (The data used be referred to ‘‘standard population’’ proposed by Kalkstein and Davis, 1989).

Although we determined the matrix of correlations between each variable used, for each cause of mortality and morbidity from each locality and hospital, it would be out of the scope of the present work to include this here. Instead, we decided to show (Table 5) only the multiple linear regressions, expressing the different coefficients obtained and the coefficient of determination (R^2), illustrative of the percentage of total variance explained by the regressions.

From the regression coefficients obtained upon relating the daily mortality series with the atmospheric and pollutants variables (Table 5), it may be deduced that the mortality due to respiratory causes is the one with the strongest association with the set of variables employed, although in Palencia and Zamora mortality due to cardiovascular causes shows the best association. The latter cause of death shows a dependence on the other six localities that is slightly lower than deaths due to respiratory causes, whereas those caused by digestive disease show a significantly lower degree of relationship. In all cases, air temperature shows negative values in the regression coefficients, indicating with this that as the air temperature value decreases mortality increases. Relative humidity, solar radiation, atmospheric pressure and wind speed show an alternance with respect to the sign of the coefficients corresponding to the different places, and hence no conclusions regarding these

Table 5. Summary of parameter estimates from linear regression analysis for all independent variables included in a model with the mortality due to all causes as the dependent variable. (R^2: squared multiple correlation coefficient).

Dependent	Independent (B) Regression coefficient											R^2
	Const.	T	RH	SR	P	WV	SO_2	O_3	NO	NO_2	CO	
Ávila												
Cardiovasc.	3.966		-0.012			0.743		-0.011				0.21
Respiratory	-8.318	-0.016	-0.013	-0.003	-0.012	0.286	-0.028	-0.008		-0.007		0.50
Digestive	0.860			-0.002		0.159	-0.031	-0.004		0.002		0.29
Burgos												
Cardiovasc.	-25.784	-0.047	0.027	-0.001	0.003	-0.418	-0.019					0.33
Respiratory	-24.991	-0.052	0.016	-0.215	0.028		0.007	0.005				0.41
Digestive	0.628	-0.004		0.001		-0.079	-0.007	0.007				0.27
León												
Cardiov.	2.723	-0.019				-0.316	0.004			-0.004	0.039	0.26
Respiratory	24.199	-0.035	-0.010	0.001	-0.025		0.008		0.014	-0.031	0.030	0.55
Digestive	12.956	-0.009	-0.005		-0.014		-0.001		0.003			0.20
Salamanca												
Cardiovasc.	14.304	-0.045			-0.012		0.007		0.001	0.005		0.54
Respiratory	7.519	-0.022	-0.003		-0.007	0.371	-0.002	-0.004	0.002	0.010		0.58
Digestive	0.132	-0.008	0.003			-0.061		0.005	0.001			0.17
Valladolid												
Cardiovas	2.532	-0.035				-0.011	0.003		0.004			0.40
Respiratory	2.273	-0.022	0.002	-0.001	-0.001	-0.006	0.006	0.003	0.009	-0.016		0.48
Digestive	0.993	-0.005			-0.001	-0.004		0.002		-0.005		0.11
Zamora												
Cardiovasc.	3.706	-0.062					0.033			-0.009	0.226	0.52
Respiratory	-4.593	-0.039	-0.005		0.006	0.493			-0.009	-0.007	0.316	0.39
Digestive	-0.942	-0.004	0.005			-0.209	0.012	0.006		0.016		0.29
Palencia*												
Cardiovasc.	2.858						-0.012		0.018	-0.028	0.509	0.27
Respiratory	1.562							-0.008		-0.003		0.13
Digestive	0.791							-0.004	-0.002		0.057	0.08

*Atmospheric variables not available.

variables can be drawn. Regarding the atmospheric pollutants analyzed, it is interesting that SO_2, O_3 and NO_2 are the compounds with the greatest association with the mortality values, NO and CO being relegated to a secondary plane.

With respect to the regression coefficients and coefficients of determination obtained for the morbidity series (Table 6), it may be seen that, as in the results obtained for mortality, the causes of respiratory origin are those with the strongest association with the set of variables and atmospheric pollutants. The exception is the hospital in Burgos, where the main causes are digestive, with a significantly lower determination coefficient than the other hospitals analyzed. In second place, the number of hospital admissions due to cardiovascular reasons are those showing the highest association with respect to the variables/atmospheric pollutants, the causes of digestive origin occupying the last position. Analysis of the data with specific reference to the variables and pollutants considered points of similar characteristics to those described for the mortality series, and is therefore not mentioned here.

4. Discussion and conclusions

As mentioned in the Introduction, in research carried out during the first half of the twentieth century the impact of atmospheric pollution on mortality and morbidity became clear, affecting

Table 6. As in Table 5, for hospital admissions (morbidity).

Dependent		Independent (B) Regression coefficient										R^2
	Const.	T	RH	SR	P	WV	SO_2	O_3	NO	NO_2	CO	
Ávila												
Cardiovasc.	-15.530				0.026	1.017	0.038	-0.009		0.038		0.27
Respirat.	3.192	-0.136	-0.016	0.013			0.363	-0.024	-0.009		-1.613	0.47
Digestive	-22.423		-0.039		0.041	0.878		-0.029			-1.257	0.19
Burgos												
Cardiovasc.	1.162			0.008		0.789	0.031					0.15
Respirat.	9.767	-0.256	-0.077	0.008			0.053					0.14
Digestive	78.215	0.121	-0.105	0.004	-0.075	1.048	0.021	-0.044				0.21
León												
Cardiovasc.	-136.369	-0.423	-0.125	0.015	0.185		-0.088	-0.035	0.047	-0.071	0.194	0.58
Respirat.	-25.995	-0.254	-0.047	0.008	0.044	-1.147	-0.017	-0.005	0.030	-0.067		0.67
Digestive	-141.393	-0.363	-0.073	0.017	0.183		-0.074	-0.042		-0.017	0.185	0.62
Salamanca												
Cardiovasc.	11.172	-0.086	0.022	0.004	-0.008	0.449				0.047		0.48
Respirat.	35.427	-0.059	0.015		-0.035	0.399	0.039	-0.008		0.035		0.68
Digestive	-2.754	0.056	0.021	0.003	0.009	-0.471	0.074	-0.024	-0.017	0.018		0.25

the respiratory system in particular. It was also observed that the incidence of this was higher in people who had previously suffered from cardiorespiratory disturbances (Helfand, 2001). For many years, the attention of investigators focused mainly on the respiratory effects caused by pollution, but recent epidemiological and experimental studies (Burnett *et al*., 1998; Goldberg *et al*., 2003; Jaffe *et al*., 2003, among others), have shown that exposure to different atmospheric pollutants also has a direct effect on the circulatory system. In general, the magnitude of this latter association is similar to that estimated for respiratory diseases, although the impact of atmospheric pollution on mortality and morbidity of cardiovascular origin is greater due to the higher rate of incidence of these latter diseases.

Taking into account the magnitude of the association, the distribution of the different pollutants and diverse indicators of health in the population, Künzli *et al*. (2000) have estimated the impact the atmospheric pollution exerts on the different indicators of three European countries, finding in all cases that hospital admissions and deaths due to cardiovascular disease surpass those due to respiratory causes.

We found positive and statistically significant associations between variations in the concentration levels of SO_2, O_3 and NO_2 with respect to daily mortality and morbidity, principally among individuals older than 69 years at the time of death. These associations were consistent with a linear relationship. We found greater excess mortality and morbidity for cardiovascular-type diseases than for respiratory deaths or admissions. Our values are within the ranges that have been reported in the literature (Schwartz and Dockery, 1992; Sunyer *et al*.,1996; Michelozzi *et al*.,1998; Ballester *et al*., 2001).

In conclusion, the present results offer evidence of a clear relationship between environmental conditions and the levels of atmospheric pollutants with mortality and the number of hospital admissions in different places in Castilla-León in Spain. Increases or decreases in variables such as temperature, the relative humidity of the air or solar radiation, among others, are associated with an increase in the number of deaths or hospital admissions, especially those due to respiratory causes, which are followed by those of cardiovascular origin. There is also evidence of an association between variations in the concentration levels of SO_2, O_3 and NO_2 with respect to daily mortality and morbidity, although this aspect requires further investigation aimed at quantifying this relationship. Additionally, the results described here are consistent with those of other studies carried out both in Spain and other countries, showing that this type of analysis may be useful in making up policies on public health.

In agreement with Loomis (2000), we believe that the results should be interpreted with certain caution. Atmospheric pollution is a complex mixture whose levels and composition may vary considerably from one place to another due to local or climatological differences. These differences can account for the divergences found in the different studies and point to the low likelihood of finding a single indicator of atmospheric pollution to which most of the observed effects can be attributed. So, our study results' may only suggest the existence of a relationship that should be confirmed by other study with different statistical methods before to be considered conclusive.

Acknowledgments

This study was funded by Research Project Grant SA008/01 from the Castilla-León Regional Education and Culture Authority. We thank the Regional Institute of Health (SACYL) for providing the health data.

References

Alberdi J. C., J. Díaz, J. C. Montero and I. Mirón, 1998. Daily mortality in Madrid community (Spain) 1986-1991: relationship with atmospheric variables. *Eur. J. Epidemiol.* **14**, 571-578.

Álvarez E., F. de Pablo, C. Tomás and L. Rivas, 2000. Spatial and temporal variability of ground-level ozone in Castilla-León (Spain). *Int. J. Biometeorol.* **44**, 44-51.

Ballester F., J. M. Tenías and S. Pérez-Hoyos, 2001 Air pollution and emergency hospital admissions for cardiovascular diseases in Valencia, Spain. *J. Epidemiol. Commun. Health.* **55**, 57-65.

Burnett R. T., S. Cakmak, M. E. Raizenne, D. Stieb, R. Vincent, D. Krewski, J. R. Brook, O. Philips and H. Ozkaynak, 1998. The association between ambient carbon monoxide levels and daily mortality in Toronto, Canada. *J. Air Waste Manag. Assoc*. **48**, 689-700.

Calderón C., J. Lacey, A. McCartney and I. Rosas, 1997. Influence of urban climate upon distribution of airborne Deuteromycete spore concentrations in México City. *Int. J. Biometeorol.* **40**, 71-80.

Díaz J., C. López, J. C. Alberdi, A. Jordan, R. García, E. Hernández and A. Otero, 2001. Heat waves in Madrid, 1986-1997: effects on the health of the elderly. *Int. Arch. Occup. Environ. Health* **75**, 163-170.

Fairley D., 1990. The relationship of daily mortality to suspended particulates in Santa Clara County, 1980-1986. *Environ. Health Persp*. **89**, 159-168.

Firket J., 1931 The cause of the symptoms found in the Meuse Valley during the fog of December 1930. *Bull. Acad. Roy. Med. Belg*. **11**, 683-741.

Font I., 1983. *Climatología de España y Portugal*. Instituto Nacional de Meteorología, Madrid, 296 pp.

García L. and A. Reija, 1994. *Tiempo y clima en España. Meteorología de las Autonomías.* Dossat, Madrid, 410 p.

Goldberg M. S., R. T. Burnett, M. F. Valois, K. Flegel, J. C. Bailar, J. Brook, R. Vincent and K. Radon, 2003. Associations between ambient air pollution and daily mortality among persons with congestive heart failure. *Environ. Res*. **91**, 8-20.

González S., J. Díaz, M. S. Pajares, J. C. Alberdi, A. Otero and C. López, 2001. Relationship between atmospheric pressure and mortality in the Madrid Autonomous Region: a time-series study. *Int. J. Biometeorol*. **45**, 34-40.

Guest C. S., K. Willson, A. Woodward, K. Hennessy, L. S. Kalkstein, C. Skinner and A. J. McMichael, 1999. Climate and mortality in Australia: retrospective study: 1979-1990, and predicted impacts in five major cities in 2030. *Climate Res*. **13**, 1-15.

Helfand W. H., J. Lazarus and P. Theerman, 2001. Donora, Pennsylvania: an environmental disaster of the 20th century. *Amb. J. Public Health.* **91**, 553.

HMSO, 1954. Mortality and morbidity during the London fog of December 1952. London. *Public Health and Subjects.* 95.

Jaffe D. H., M. E. Singer and A. A. Rimm, 2003. Air pollution and emergency department visits for asthma among Ohio Medicaid recipients, 1991-1996. *Environ. Res*. **91**, 21-28.

Kalkstein L. and R. Davis, 1989. Weather and human mortality: an evaluation of demographic and interregional responses in the United States. *Annals of the Association of American Geographers* **79**, 44-64.

Künzil N., R. Kaiser, S. Medina, M. Studnicka, O. Chanel, P. Filliger, M. Herry, F. Horvak Jr. V. Puybonnieux-Texier, P. Quenel, J. Schneider, R. Seethaler, J. Vergnaud and H. Sommer, 2000. Public health impact of outdoor and traffic-related air pollution: an European assessment. *Lancet* **356**, 795-801.

Loomis D., 2000. Sizing up air pollution research. *Epidemiology*. **11**, 2-4.

McGregor G. R., S. Walters and J. Wordley, 1999. Daily hospital respiratory admissions and winter air mass types, Birmingham, UK. *Int. J. Biometeorol*. **43**, 21-30.

McKendry I. G., 1993. Ground level ozone in Montreal, Canada. *Atmos. Environ*. **27B**, 93-103.

Michelozzi P., F. Forastiere, D. Fusco, C. A. Perucci, B. Ostro, C. Ancona and G. Pallotti, 1998. Air pollution and daily mortality in Rome, Italy. *Occup. Environ. Med*. **55**, 605-610.

Ostro B., J. M. Sánchez, C. Aranda and G. S. Eskeland, 1996. Air pollution and mortality: results from a study of Santiago, Chile. *J. Expo. Anal. Environ. Epidemiol*. **6**, 97-114.

Panero C., F. de Pablo and C. Tomás, 1997. Statistical modelling and prediction of pollutants in the urban atmosphere of Salamanca, Spain. *Int. J. Biometeorol*. **40**, 223-233.

Pope C.A. III, J. Schwartz and M.R. Ransom, 1992. Daily mortality and PM_{10} pollution in Utha Valley. *Arch. Environ. Health.* **47**, 211-217.

Prior S. C. and D. G. Steyn, 1995. Hebdomadal and diurnal cycles in ozone time series from the Lower Fraser Valley, C. B. *Atmos. Environ*. **32**, 123-131.

Sáez M., J. Sunyer, J. Castellsagué, C. Murillo and J.M. Antó, 1995. Relationship between weather temperature and mortality: a time series analysis approach in Barcelona. *Int. J. Epidemiol.* **24**, 576-582.

Saldiva P. H., C. A. Pope III, J. Schwartz, D. W. Dockery, A. J. Lichtenfels, J. M. Salge, I. Barone and G. M. Bohm, 1995. Air pollution and mortality in elderly people: a time series study in Sao Paulo, Brazil. *Arch. Environ. Health.* **50**, 159-163.

Schwartz J. and D. W. Dockery, 1992. Particulate air pollution and daily mortality in Steubenville, Ohio. *Amb. J. Epidemiol*. **135**, 12-19.

Schwartz J., 1994. Total suspended particulate matter and daily mortality in Cincinnati, Ohio. *Environ. Health Persp*. **102**, 186-189.

Seoánez M., 1996. *Ingeniería del medio ambiente aplicada al medio natural continental*. Mundi-Prensa, Madrid, 1111 p.

Shrenk N., H. Heimann and G. Clayton, 1949. Air pollution in Donora PA: epidemiology of the unusual smog episode of October 1948. Preliminary report. Washington, DC: US. Public Health Service, 306.

Shumway R. H., A. S. Azari and Y. Pawitan, 1988. Modeling mortality fluctuations in Los Angeles as functions of pollution and weather effects. *Environ. Res*. **45**, 224-241.

Smith J., R. Davis, J. Sacks, P. Speckman and P. Styer, 2000. Regression models for air pollution and daily mortality: analysis of data from Birmingham, Alabama. *Envirometrics* **11,** 719-743.

Smoyer K., L. S. Kalkstein, J. Greene and H. Ye, 2000. The impacts of weather and pollution on human mortality in Birmingham, Alabama and Philadelphia, Pennsylvania. *Int. J. Climatol.* **20**, 881-897.

Sunyer J., J. Castellsagué, M. Sáez, A. Tobías and J. M. Antó, 1996. Air pollution and mortality in Barcelona. *J. Epidemiol. Commun. Health.* **50**, Suppl 1: s76-s80.

Toulomi G., E. Salomi and K. Katsouyanni, 1996. Daily mortality and "winter type" air pollution in Athens, Greece - A time series analysis within the APHEA Project. *J. Epidemiol. Commun. Health.* **50**, 47-51.

Yuanzhang L. and D. Roth, 1995. Daily mortality analysis by using different regression models in Philadelphia County, 1973-1990. *Inhal. Toxicol*. **7**, 45-48.