Environ Sci Pollut Res (2015) 22:7012–7019
DOI 10.1007/s11356-014-3916-2

RESEARCH ARTICLE

Influence of advections of particulate matter from biomass combustion on specific-cause mortality in Madrid in the period 2004–2009

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Received: 12 September 2014 / Accepted: 24 November 2014 / Published online: 9 December 2014

Abstract Approximately, 20 % of particulate and aerosol emissions into the urban atmosphere are of natural origin (including wildfires and Saharan dust). During these natural episodes, PM_{10} and $PM_{2.5}$ levels usually exceed World Health Organisation (WHO) health protection thresholds. This study sought to evaluate the possible effect of advections of particulate matter from biomass fuel combustion on daily specific-cause mortality among the general population and the segment aged ≥75 years in Madrid. Ecological time-series study in the city of Madrid from January 01, 2004 to December 31, 2009. The dependent variable analysed was daily mortality due to natural (ICD-10:A00-R99), circulatory (ICD-10:I00-I99), and respiratory (ICD-10:J00-J99) causes in the population, both general and aged ≥75 years. The following independent and control variables were considered: a) daily mean $PM_{2.5}$ and PM_{10} concentrations; b) maximum daily temperature; c) daily mean O_3 and NO_2 concentrations; d) advection of particulate matter from biomass combustion (http://www.calima.ws/), using a dichotomous variable and e) linear trend and seasonalities. We conducted a descriptive analysis, performed a test of means and, to ascertain relative risk, fitted a model using autoregressive Poisson regression and stratifying by days with and without biomass advection, in both populations. Of the 2192 days analysed, biomass advection occurred on 56, with mean $PM_{2.5}$ and PM_{10} values registering a significant increase during these days. PM_{10} had a greater impact on organic mortality with advection (RRall ages=1.035 [1.011–1.060]; RR≥75 years=1.066 [1.031–1.103]) than did $PM_{2.5}$ without advection (RRall ages=1.017 [1.009–1.025]; RR≥75 years=1.012 [1.003–1.022]). Among specific causes, respiratory—though not circulatory—causes were associated with PM_{10} on days with advection in ≥75 year age group. PM_{10}, rather than $PM_{2.5}$, were associated with an increase in natural cause mortality on days with advection of particulate matter from biomass combustion, particularly in the ≥75 year age group.

Keywords Biomass combustion · Particulate matter · Mortality · Elderly

Responsible editor: Gerhard Lammel

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Introduction

On a global scale, 98 % of particulate and aerosol emissions into the atmosphere come principally from natural sources (Guieré and Querol 2010), chief among which are aerosols of marine origin (84 %) and mineral dust (13 %) (Viana et al 2014), with only 2 % of such emissions being of anthropogenic origin.

On a local scale, however, this scenario changes radically, i.e. taking an urban area in southern Europe as an example, 80 % of these particulate and aerosol emissions will be seen to be linked to anthropogenic activities, while the remaining 20 % continue to have a component of natural origin, such as those stemming from advections of desert dust (Pey et al. 2013), sea spray (O'Dowd and de Leeuw 2007), volcanic emissions (Von Glasow et al. 2009) and aerosols from wildfires (Barbosa et al 2009). Recent studies (Viana et al 2014) estimate that these natural sources contribute to annual mean immission levels of particles having a diameter of under 10 micra (PM_{10}) by as much as 4 μg/m^3 in places such as Spain. Although these values might on average seem of little significance, these contributions nevertheless tend to come in episodic periods of short duration which usually result in notable exceedances of the thresholds stipulated by European directives (Official Journal European Union 2008) and the air quality guideline values established by the World Health Organisation for protection of health (WHO 2006), essentially in terms of the wide margin whereby PM_{10} and $PM_{2.5}$ (particles having a diameter of under 2.5 micra) levels are surpassed (Dennekamp et al. 2011; Finlay et al 2012).

The health effects of Saharan dust advections have been widely studied in southern Europe and many studies have linked these contributions of particles of natural origin to increased hospital admissions (Reyes et al. 2014) and daily mortality due, not only to non-accidental causes, (Jiménez et al. 2010; Tobías et al 2011) but also to specific, circulatory and respiratory causes (Perez et al. 2012; Díaz et al 2012). Few studies have however been addressed the impact of biomass-combustion particles on population health (Finlay et al 2012). Normally, such studies link wildfires to impaired lung function (Mirabelli et al 2009), increases in asthma-related hospital emergencies (Ovadnevaite et al 2006) and hospitalisations due to exacerbations related to these conditions (Lee et al 2009; Martin et al 2013). From the point of view of the relationship between daily mortality and the increase in particles from wildfires, some studies, such as one undertaken in Denver, report no association between these events and increases in daily mortality (Vedal and Dutton 2006), whereas others, such as one conducted in Athens, show that so-called medium-sized fires do indeed have an influence on increases in daily mortality (4.9 %) due both to respiratory (6.0 %) and to circulatory causes (16.2 %). These values rise by one order of magnitude in the case of large fires (Analitis et al 2012), with the effect being greater in the 75-and-over age group.

In the case of Spain, the total surface area affected by wildfires between 2008 and 2012 was 550,000 ha, according to the latest data available from the Ministry of Agriculture, Food and Environment (Magrama 2013), with 2012 being the year in which the greatest number of hectares was destroyed by fire. Forecasts of the impact of climate change on Spain (Moreno 2006) indicate an increase both in the number of wildfires and in the amount of hectares affected.

This study is placed in the city of Madrid, which constitutes a densely populated city with substantial levels of essentially traffic-related air pollution. Air quality in the capital still does not reach pollution limits set by the UE legislation, as well as those recommended by the World Health Organisation (WHO) for certain pollutants values, particulate matter with an aerodynamic diameter less 2.5 μm ($PM_{2.5}$), nitrogen dioxide (NO_2) and tropospheric ozone (O_3). The data for the annual reports on air quality imply that Madrid fails the legal limits of NO_2 and also point to a new problem for the future with the ozone (O_3) concentrations exceedance the legal limits (Ecologistas en acción 2014).

Accordingly, a study is clearly needed to analyse on daily mortality in Madrid the possible effect of advections of particulate matter from biomass combustion and advections of Sahara dust among the general population and that aged 75 years and over, which is more sensitive to the effects of air pollution.

Materials and methods

Study design

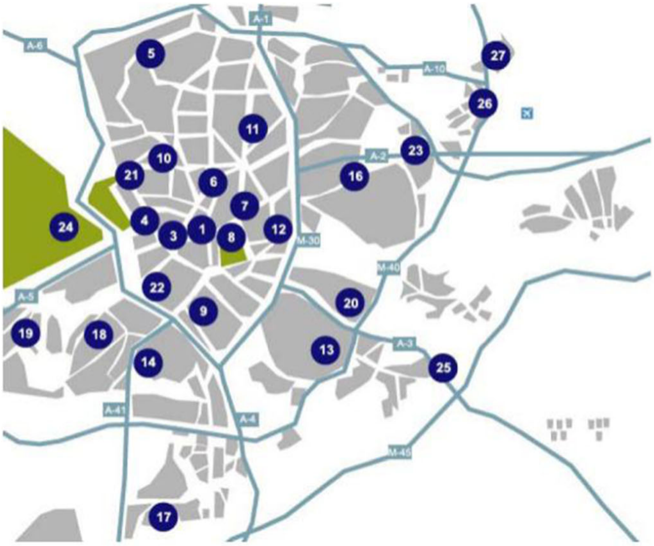
We conducted a longitudinal, ecological time-series study covering daily deaths in the population of all ages and aged 75 years and over, across the period January 01, 2004 to December 31, 2009 in the city of Madrid, stratifying our analyses by the presence or absence of advection of particulate matter from biomass combustion.

Data

The city of Madrid is a densely populated metropolitan area situated in the central region of Spain. In the period 2004–2009, it had a mean population of 3,164,245 and of this total 297,567 (9 %) were aged 75 years or over (National Statistics Institute/*Instituto Nacional de Estadística*). The dependent variable used was daily mortality due to natural (International Classification of Diseases, Tenth Revision (ICD-10): codes A00-R99), circulatory (ICD-10: codes I00-I99) and respiratory causes (ICD-10: codes J00-J99). These data were drawn from the "Consejería de Economía y Hacienda de la comunidad de Madrid".

Saharan dust intrusions are a frequent phenomenon in the Madrid atmosphere (Artiñano et al. 2004), which, moreover, register high temperatures and low precipitation (Calendario Meteorológico. State Meteorological Agency, AEMET 2014), conditions that in turn facilitate elevated levels of other types of air pollutants such as those emited by vehicular traffic. For this reason, as independent variables, we considered daily mean concentrations (μg/m^3) of chemical air pollutants $PM_{2.5}$ and PM_{10}, recorded by the respective monitoring stations distributed around the city

(27 stations in 2009) and supplied by the Madrid Municipal Air Quality Monitoring Grid (*Red de Vigilancia de la Calidad del Aire del Ayuntamiento de Madrid*). In the following figure, appears the location of stations.



01	PASEO DE RECOLETOS	CENTRO	3°41'31,00"	40°25'21,36"
03	PL. DEL CARMEN	CENTRO	3°42'11,42"	40°25'09,15"
04	PL. DE ESPAÑA	MONCLOA	3°42'44,40"	40°25'26,37"
05	BARRIO DEL PILAR	FUENCARRAL	3°42'41,55"	40°28'41,62"
06	PL. DR. MARAÑÓN	CHAMBERÍ	3°41'27,00"	40°26'15,39"
07	PL. M. SALAMANCA	SALAMANCA	3°40'49,19"	40°25'47,81"
08	ESCUELAS AGUIRRE	SALAMANCA	3°40'56,35"	40°25'17,63"
09	PL. LUCA DE TENA	ARGANZUELA	3°41'36,35"	40°24'07,68"
10	CUATRO CAMINOS	CHAMBERÍ	3°42'25,66"	40°26'43,95"
11	AV. RAMÓN Y CAJAL	CHAMARTÍN	3°40'38,47"	40°27'05,30"
12	PL. MANUEL BECERRA	SALAMANCA	3°40'06,71"	40°25'43,70"
13	VALLECAS	PUENTE VALLECAS	3°39'05,48"	40°23'17,34"
14	PL. FDEZ. LADREDA	USERA	3°42'59,71"	40°23'06,28"
15	PLAZA DE CASTILLA	TETUÁN-CHAMARTÍN	3°41'19,29"	40°28'05,73"
16	ARTURO SORIA	CIUDAD LINEAL	3°38'21,24"	40°26'24,17"
18	GENERAL RICARDOS	CARABANCHEL	3°43'54,60"	40°23'41,20"
19	ALTO EXTREMADURA	LATINA	3°44'30,83"	40°24'28,29"
20	AV. DE MORATALAZ	MORATALAZ	3°38'43,03"	40°24'28,64"
21	ISAAC PERAL	MONCLOA	3°43'04,54"	40°26'24,51"
22	PASEO DE PONTONES	ARGANZUELA	3°42'46,56"	40°24'22,95"
23	C/ ALCALÁ (Final)	SAN BLAS	3°36'34,62"	40°26'55,44"
24	CASA DE CAMPO	MONCLOA	3°44'50,44"	40°25'09,68"
25	SANTA EUGENIA	VILLA VALLECAS	3°36'09,18"	40°22'44,48"
26	URB. EMBAJADA	BARAJAS	3°34'48,42"	40°27'33,56"
27	BARAJAS PUEBLO	BARAJAS	3°34'48,10"	40°28'36,94"

Adapted from Madrid Municipal Air Quality Monitoring Grid 2009

In addition, we controlled for the following atmospheric and chemical-pollution variables:

a) Daily mean concentrations (μg/m^3) of tropospheric ozone (O_3) and nitrogen dioxide (NO_2), as supplied by the Madrid Municipal Air Quality Monitoring Grid. To estimate daily means levels of pollutans each monitor's daily concentration was averaged for that monitor and then a citywide average was calculated from all monitors for a given day.
b) Maximum daily temperature (°C), as furnished by the State Meteorological Agency (AEMET).
c) Linear trend and seasonalities, as well as the autoregressive nature of the series itself. The existence or non-existence of influenza epidemics was also included, by means of a dichotomous variable.

Days on which there was advection of particles from biomass combustion were classified by creating a dichotomous indicator variable of the daily presence or absence of advection, in what has been defined as the central area of mainland Spain (Extremadura, Castile-la Mancha, Madrid Region and Castile-León), with the necessary data being supplied by the Ministry of Agriculture, Food and Environment and the State Council for Scientific Research (*Consejo Superior de Investigaciones Científicas*) for the undertaking of studies relating to the analysis and assessment of air pollution due to particulate matter and metals in Spain (http://www.calima.ws/).

Statistical analysis

A descriptive analysis was performed, stratifying by days with and without biomass advection. This analysis consisted of calculating the mean (along with the standard deviation), and the maximum and minimum values of the variables. This was followed by a test of means for independent samples to ascertain whether there were statistically significant differences between the days with and without advection.

In view of the fact that most of the wildfires occur at times of the year with high temperatures and strong sunshine, it is especially important to control for the effect of the variables O_3 and maximum daily temperature (T_{max}), since many studies have highlighted the interaction between these and particulate matter when it comes to analysing the latter's impact on morbidity and mortality (Díaz et al 2002; De Sario et al. 2013).

Studies conducted in the city of Madrid (Díaz et al. 1999; Linares et al. 2006) indicate that ozone shows a quadratic association with mortality, with a value of 35 μg/m^3 being the vertex of the parabola. In view of the fact that days with advection are accompanied by high ozone values, only the ascending branch of this parabola was considered. Mathematically, this can be written as follows:

$$\begin{aligned} O_{3\text{high}} &= O_3 - 35 \ \ \mu\text{g/m}^3 && \text{if} \quad O_3 \geq 35 \ \ \mu\text{g/m}^3 \\ O_{3\text{high}} &= \quad 0 && \text{if} \quad O_3 < 35 \ \ \mu\text{g/m}^3 \end{aligned}$$

There is a similar V-shaped pattern between maximum daily temperature and mortality. In addition, there are two temperatures which indicate excess mortality in response to temperature extremes, i.e., one, in the case of heat, set at a daily maximum of 36.5 °C (Díaz et al 2002), and the other, in the case of cold, set at a daily maximum of 5 °C (Diaz et al. 2005). To take this effect of temperature on mortality into account, both on days with advection, on which high temperatures are frequent, and on those without advection, the variables T_{hot} and T_{cold} were created as follows:

$$\begin{array}{lllll} T_{hot} & = & T_{max}-36.5\ ^{\circ}C & \text{if} & T_{max} \geq 36.5\ ^{\circ}C \\ T_{hot} & = & 0 & \text{if} & T_{max} < 36.5\ ^{\circ}C \\ T_{cold} & = & 5\ ^{\circ}C - T_{max} & \text{if} & T_{max} \leq 5\ ^{\circ}C \\ T_{cold} & = & 0 & \text{if} & T_{max} > 5\ ^{\circ}C \end{array}$$

Due to the Poissonian nature of the mortality variables and to correct residual autocorrelation, we chose to fit an autoregressive Poisson regression model, including among the explanatory variables a lag (lag 1) of the dependent variable (Besag 1974) (Saez et al. 1999). The models for the three causes of mortality were controlled for environmental variables (O_3 and T_{max} were replaced by their transformed variables O_{3high}, T_{hot} and T_{cold}) and their lags, until lag 4 in the case of $PM_{2.5}$ and PM_{10}, as indicated by other studies that link morbidity and mortality (Tobías et al. 2011; Jiménez et al 2010). We also controlled for trend and seasonalities. The results of the final models were expressed in the form of relative risks (RRs) and their 95 % confidence intervals for statistically significant variables (p<0.05). These RRs are shown for each 10 μg/m^3 increase in the case of the chemical air pollutants and for each 1 °C increase in the case of temperature.

All analyses were performed using the SPSS v22 (SPSS: an IBM company) and Stata/SE 11.2 (StataCorp LP) software programmes.

Results

Of the 2192 days analysed, advections of particulate matter from biomass combustion were observed on 56 days in the city of Madrid (Table 1). On average, 59.9 persons—68 % aged 75 years and over—died due to natural causes on days without advection (SD, 10.9) versus 53 persons (SD, 9.0)—65 % aged 75 years and over—on days with advection. This indicates a reduction in the age of those who died on days with advection of wildfire-smoke particles.

A statistically significant increase (p<0.001) was observed in the mean values of the chemical air pollutants $PM_{2.5}$, PM_{10} and O_3 on days with advection ($PM_{2.5}$, 23.6 vs. 16.9; PM_{10}, 44.2 vs. 31.1; O_3, 48.0 vs. 36.4). $PM_{2.5}$ concentrations exceed the WHO thresholds in Madrid during the study period in 327 days: 303 days without advection of biomass (14.1 %) and 24 days with advection of biomass (42.8 %). PM_{10} concentrations exceed the WHO thresholds in Madrid during the study period in 270 days: 249 days without advection of biomass (11.6 %) and 21 days with advection of biomass (37.5 %).

Table 2 shows the RRs associated with factors which had a significant effect on daily mortality due to specific causes (natural, respiratory and circulatory) in the general population and population aged 75 years and over, by reference to the presence/absence of biomass advection. In general, on days with biomass advection, it was PM_{10} particles that had an effect on daily natural-cause mortality, whereas on days without advection, it was $PM_{2.5}$ particles that had an effect on all the causes of mortality analysed. At all events, this effect was short-term, remaining in evidence until 4 days after (lag 4) the initial increase in daily mean PM_{10} or $PM_{2.5}$ concentrations.

The impact of PM_{10} particles on daily natural-cause mortality on days with advection was greater ($RR_{all\ ages}$=1.035 [1.011–1.060]; $RR_{\geq 75\ years}$=1.066 [1.031–1.103]) than that of $PM_{2.5}$ particles on days without advection ($RR_{all\ ages}$=1.017 [1.009–1.025]; $RR_{\geq 75\ years}$=1.012 [1.003–1.022]), regardless of the study population.

In the population aged 75 years and over, the factors T_{hot} and O_{3high} also registered statistically significant effects on natural-cause mortality, both in the presence and in the absence of advection.

Discussion

The results in Table 1 show that on days with advection of particulate matter from biomass combustion, concentrations of both PM_{10} and $PM_{2.5}$ particles are significantly higher than on days without such advection. Although the increase occurs in both fractions of particulate matter analysed, it is nonetheless slightly higher in PM_{10} than in $PM_{2.5}$, with a 42.2 % versus a 39.6 % increase, which contradicts the assertion that it is $PM_{2.5}$ particles which are predominant in wildfire smoke (Naeher et al. 2007; Sapkota et al 2005).

A direct consequence of these increases in particulate matter concentrations on days with advection is that WHO health-protection thresholds (WHO 2006) are not merely exceeded but rise to practically triple the permitted value for both PM_{10} (observed concentrations of up to 150 μg/m^3) and $PM_{2.5}$ (observed concentrations of up to 71 μg/m^3). These maximum concentrations on days with advection from combustion of biomass fuels are very much higher than those measured on days without advection, though they are still far below the PM_{10} values of up to 500 μg/m^3 recorded elsewhere (Naeher et al. 2007; Finlay et al 2012; Boman et al 2003; Dennekamp and Abramson 2011). If, rather than daily maximum values, daily mean concentrations are instead analysed in relation to

Table 1 Descriptive statistics of daily specific-cause mortality in the general population and population aged ≥75 years, chemical air pollutants and maximum temperatures in Madrid during the study period (January 01, 2004–December 31, 2009)

		Days without advection (N=2136 days)					Days with advection (N=56 days)				
	Mortality rate[a]	Mean	SD	Min	Max	Mortality rate[a]	Mean	SD	Min	Max	p value
Daily deaths—all population											
Total natural causes (ICD-10: A00-R99)	1.89	59.9	10.90	32.0	109.0	1.67	53.0	9.00	35.0	82.0	<0.001
Respiratory causes (ICD-10: J00-J99)	0.30	9.6	4.10	1.0	32.0	0.24	7.6	3.12	2.0	16.0	<0.001
Circulatory causes (ICD-10: I00-I99)	0.57	17.9	5.16	5.0	40.0	0.48	15.1	4.04	7.0	27.0	<0.001
Daily deaths population ≥75 years											
Total natural causes (ICD-10: A00-R99)	13.7	40.8	8.64	18.0	74.0	11.52	34.3	7.11	21.0	55.0	<0.001
Respiratory causes (ICD-10: J00-J99)	2.69	8.0	3.58	0.0	28.0	2.04	6.1	2.44	2.0	12.0	<0.001
Circulatory causes (ICD-10: I00-I99)	4.74	14.1	4.34	4.0	33.0	3.83	11.4	3.46	5.0	23.0	<0.001
Particulate matter											
$PM_{2.5}$ (μg/m^3)		16.9	7.75	3.4	71.4		23.6	7.81	7.7	41.3	<0.001
PM_{10} (μg/m^3)		31.1	15.80	0.0	149.5		44.2	14.66	13.6	76.9	<0.001
Other pollutants											
NO_2 (μg/m^3)		58.5	18.40	17.6	133.5		62.6	19.91	30.3	106.0	0.097
O_3 (μg/m^3)		36.4	18.29	5.1	88.8		48.0	18.97	7.6	79.1	<0.001
Weather											
Max. temperature (°C)		20.0	8.73	1.0	38.4		30.1	5.26	15.0	28.0	<0.001

SD standard deviation, *Min* minimum, *Max* maximum

[a] Mean mortality rate calculated for the study period ×100,000 inhabitants

Table 2 Relative risks and 95 % confidence intervals of the variables with statistically significant effects on specific-cause mortality in the general population and population aged ≥75 years, by reference to advections of particulate matter from biomass combustion in Madrid during the study period (January 01, 2004–December 31, 2009)

	All ages			Ages ≥75 years		
	Variable	RR	95 % CI	Variable	RR	95 % CI
Days without advection						
Total natural causes (ICD-10: A00-R99)	$PM_{2.5}$ (lag 1)	1.017	1.009–1.025	$PM_{2.5}$ (lag 3)	1.012	1.003–1.022
	T_{hot} (lag 0)	1.072	1.015–1.133	T_{hot} (lag 0)	1.099	1.029–1.174
	T_{hot} (lag 3)	1.082	1.024–1.144	T_{hot} (lag 3)	1.080	1.009–1.155
	NO_2 (lag 0)	1.005	1.002–1.009	NO_2 (lag 1)	1.011	1.007–1.015
				O_{3high} (lag 3)	1.013	1.004–1.022
Respiratory causes (ICD-10: J00-J99)	$PM_{2.5}$ (lag 4)	1.036	1.017–1.055	$PM_{2.5}$ (lag 1)	1.045	1.024–1.067
				$PM_{2.5}$ (lag 4)	1.030	1.009–1.051
Circulatory causes (ICD-10: I00-I99)	$PM_{2.5}$ (lag 0)	1.026	1.012–1.040	$PM_{2.5}$ (lag 0)	1.029	1.015–1.044
	T_{hot} (lag 2)	1.115	1.005–1.236			
	T_{cold} (lag 2)	1.045	1.002–1.090			
Days with advection						
Total natural causes (ICD-10: A00-R99)	PM_{10} (lag 2)	1.035	1.011–1.060	PM_{10} (lag 2)	1.066	1.031–1.103
				T_{hot} (lag 2)	1.247	1.061–1.465
				O_{3high} (lag 1)	1.061	1.007–1.119
Respiratory causes (ICD-10: J00-J99)	No statistical association			PM_{10} (lag 2)*	1.061	0.989–1.138
Circulatory causes (ICD-10: I00-I99)	T_{hot} (lag 0)*	1.231	0.957–1.583	No statistical association		

RR relative risk, *95 % CI* 95 % confidence interval

*p value<0.10

WHO guideline values, it will be seen that the $PM_{2.5}$ threshold is exceeded on 42.8 % of days with advection versus 14.1 % of days without advection; and that, in the case of PM_{10}, the health protection threshold is exceeded on 37.5 % of days with advection versus 11.6 % of days without advection. This higher number of exceedances of the protection threshold registered in data pertaining to wildfires has already been described elsewhere (Naeher et al. 2007; Finlay et al 2012; Boman et al 2003; Dennekamp and Abramson 2011). Of the other two pollutants measured, it should be noted that the difference observed between mean NO_2 concentrations on days with and without biomass advection highlights the anthropic nature of this pollutant. In the case of O_3, the conditions of strong sunshine and high temperatures which are present in the major part of wildfires, and are also necessary for the formation of O_3 from its precursors, account for the fact that ozone concentrations are higher on days with than on days without biomass advection (Azevedo et al 2011).

Exceedance of WHO thresholds on days with advection is reflected in the results of Table 2, in which the impact of particulate matter on daily mortality is analysed.

The relationship between particulate matter and daily mortality on days without advection from biomass combustion is similar to that already described for the city of Madrid in other studies, for the general population (Maté et al 2010; Guaita et al 2011) and the population aged 75 years and over (Jiménez et al 2010). Yet, when this relationship is analysed on days with biomass advection, it will be seen as follows: firstly, that $PM_{2.5}$ is no longer the indicator of particles which are associated with mortality but that this role now passes to the coarser PM_{10} particles; and secondly, that this latter effect is greater (with advection (PM_{10}): $RR_{\text{all ages}}$=1.035 [1.011–1.060]; without advection ($PM_{2.5}$): $RR_{\text{all ages}}$=1.017 [1.009–1.025]). In the case of persons aged over 75 years, this risk is multiplied by 5 (with advection (PM_{10}): $RR_{\geq 75\ \text{years}}$=1.066 [1.031–1.103]; without advection ($PM_{2.5}$): $RR_{\geq 75\ \text{years}}$=1.012 [1.003–1.022]), with this difference being statistically significant. This change in the particulate-matter indicator with respect to mortality for days with and without advection is similar to what occurs when there are Saharan dust intrusions (Jiménez et al 2010; Reyes et al 2014), and would appear to indicate that it is the greater size rather than the composition of particulate matter which is more closely related to this association (Pérez et al. 2008). Similar conclusions have been reached from a toxicological standpoint (Finlay et al 2012). The difference between urban and wildfire smoke was also illustrated by a study that examined the effect on macrophages exposed to wildfire and urban smoke in a murine model (Jalava et al 2006). This showed that, although cytokine production in response to wildfire smoke was lower than with urban-derived particles, there was more inflammatory (determined by measuring proinflammatory cytokines) and cytotoxic activity (as measured by biochemical markers of toxicity, apoptotic and nitrous oxide production) per cubic metre of air containing wildfire particles than with air containing only urban particulate matter. This was probably a result of a higher concentration of PM_{10} particles in the wildfire smoke. This increased particulate size means that particles can accumulate in the lung more easily. In addition, volatile organic compounds present in wildfires (Garcia-Hurtado et al. 2014) could be absorbed into the surface of the particles (Finlay et al 2012), thus increasing their toxicity.

From the perspective of increases in risk, higher in the group aged over 75 years, it should be stressed that similar results have been reported by the few studies which have analysed the relationship between wildfires and mortality in large cities (Analitis et al 2012; Ignotti et al. 2010).

Furthermore, the finding that it is respiratory-cause rather than circulatory-cause mortality that shows an association with particulate matter is in line with the literature on this point. Indeed, the in-depth review of the literature on wildfires and morbidity/mortality associated with respiratory diseases conducted by Sario et al. (De Sario et al. 2013) showed that the closest association was with exacerbation of cases of asthma, chronic obstructive pulmonary disease, reduced lung capacity and upper-respiratory-tract problems, and with especially vulnerable groups such as the elderly and children.

Additionally, the results obtained by our study, in which high temperatures and high tropospheric ozone levels were shown to be significantly associated with natural-cause mortality on days with biomass advection, go to underscore the need for control of these variables which are so present in the majority of wildfires (Grumm 2010). Nevertheless, the synergic effect that high temperatures have on particle behaviour, and the many interactions between heat and particulate matter, highlighted in many multicentre and case-crossover studies (Zmirou et al 1998; Anderson et al 2001; Stafoggia et al. 2008; Stieb et al 2009), and between heat and ozone (Zmirou et al 1998; Díaz et al 2002), could modify the results observed in this study. Moreover, the source of data on particulate matter recorded at stations located at points chosen to measure air pollution of urban origin might not accurately represent the real levels of such particulate matter (De Sario et al. 2013). Moreover, the use of fixed exposure monitoring sites to infer exposures of individuals across relatively large geographic areas may lead to potential misclassifications exposure (Berkson-type measurement error). Our study suffered from other additional limitations, firstly, a major potential limitation of ecological studies is the ecological fallacy; an erroneous classification of mortality causes or not controlling for other variables associated with mortality as pollen concentrations or noise levels as other analysis in Madrid city made (Maté et al 2010; Jiménez et al. 2010). This study has several strengths also, to date, very few published studies exits in Spain that evaluate the health effects of biomass combustion. Moreover, a large number of stations validated for the environmental data are used and there is a comprehensive control of the atmospheric variables implied (pollutants and temperature). Lastly, the results obtained show consistency with previous studies for Madrid on health impact of air pollution (Reyes et al 2014).

If the impact of climate change on wildfires (IPCC 2013) is taken into account, then in the near future, the ageing of the population, rise in chronic diseases and socio-economic changes may very well increase the risk population (Mannino and Buist 2007; McMichael et al 2006) exposed to the consequences that wildfires have on large cities, even where far removed from the principal foci of the blaze. Hence, there is a real need for better knowledge of the mechanisms implicated in the morbidity and mortality processes associated with advections of particulate matter from biomass combustion, so that preventive measures can be implemented to minimise their impact on population health.

Acknowledgments This was a strategic health action funded by the FIS Project: ENPY 1001/13 and the SEPY-1037/14 project.

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