Health effects from Sahara dust particles

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Angeliki Karanasiou, Natalia Moreno, Teresa Moreno, Mar Viana, Frank de Leeuw, Xavier Querol

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Front page picture:
Sahara with dust particles in the atmosphere being transported to and deposited in Europe; beeldbank RIVM

Author affiliation:
Angeliki Karanasiou, Natalia Moreno, Teresa Moreno, Mar Viana, Xavier Querol: Institute of Environmental Assessment and Water Research (IDAEA-CSIC), Barcelona, Spain
Frank de Leeuw: National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands

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ETC/ACM Technical Paper 2011/4
European Topic Centre on Air Pollution and Climate Change Mitigation
PO Box 1
3720 BA Bilthoven
The Netherlands
Phone +31 30 2748562
Fax +31 30 2744433
Email etcacm@rivm.nl
Website http://acm.eionet.europa.eu/

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1. Introduction

During the last years there has been an increasing interest in the study of atmospheric aerosols given their confirmed impact on human health. A large number of epidemiological studies demonstrated that atmospheric particulate matter (PM) has a clear correlation with the number of daily deaths and hospitalizations as a result of respiratory, cardiovascular and cardiovascular diseases. However, a limited number of studies have been carried out to establish the health effects due exclusively to the Saharan dust source. For this reason, the objective of this work is to review the literature to determine if Saharan dust particles have a relevant impact on human health. Additionally, this study expresses the need for determining the possible effects of Saharan dust exposure. These effects may depend on temporal variability, frequency and prediction of the Saharan dust events, PM concentration, composition and size, among others. The results of the current review may be considered to establish the objectives and strategies of the new European 2013 directive on atmospheric particle levels.

2. Description of Sahara dust episodes

Dust outbreaks may greatly increase the ambient air levels of PM recorded in air quality monitoring networks. This is especially relevant in Southern Europe (Querol et al., 1998; Rodriguez et al., 2001; Escudero et al., 2005,2007; Kallos et al., 2007; Mitsakou et al., 2008; Gerasopoulos et al., 2006; Kocak et al., 2007), Eastern Asia (Zhang and Gao, 2007) and in some Atlantic islands (Prospero and Nees, 1986; Coudé-Gaussen et al., 1987; Chiapello et al., 1995; Arimoto et al., 1997; Viana et al., 2002).

The transport of Saharan dust into Europe has a clear seasonality, being more frequent from February to June, and from late autumn to early winter (Escudero et al., 2005), although dust events can be distributed throughout the year. The Mediterranean countries are mostly affected by Sahara dust episodes (Querol et al., 2009; Kallos et al., 2007). The reason for this is the low precipitation in the Mediterranean basin that favours the long residence time of PM in the atmosphere with the consequent impact on air quality. It should be noted, that >70 % of the exceedances of the PM_{10} daily limit value (2008/50/CE European Directive) in most regional background (RB) sites of Spain have been attributed to dust outbreaks (Escudero et al., 2007). Similar findings are mentioned in Gerasopoulos et al. (2006), Kocak et al. (2007) and Mitsakou et al. (2008) for the Eastern Mediterranean Basin. Figure 1 shows the number of exceedances of the EU PM_{10} limit value in regional background sites in Europe for the period 2000-2007. Regional background PM_{10} levels across the Mediterranean show clear increasing trends from the north to south and western to eastern of the Basin. These trends are almost coincident with the PM_{10} African dust load (Figure 2). Previously, Querol et al. (2009) revealed a higher probability of elevated PM levels (>100 $\mu g/m^3$) occurrence in the Eastern Mediterranean Basin rather than in the Western Mediterranean Basin owing to the higher occurrence and intensity of African dust intrusions.

The particle size of desert dust lies in the coarse mode as 48 % of the total suspended particles (TSP) are particles with an aerodynamic diameter ≤ 10 µm (Goudie and Middleton, 2006), with suspension being the main mechanism of dust transport. Thus, silt is expected to be a dominant component, although clay and sand fractions can also be present, as dust deposits tend to get finer with increasing distance from their source regions. There has been a considerable amount of work in characterising African aerosol chemistry, mainly using major element variations (e.g. Moreno et al., 2006), and on chemical variations linked to particle size fractionation. The chemical composition of dust is mostly dominated by SiO_2 (59.99%), Al_2O_3 (14.13%), Fe_2O_3 (6.85%), CaO (3.94%), MgO (2.60%) and K_2O (2.35%) (Goudie and

Middleton, 2006). Mineralogically, this composition relates to dominance of quartz, magnetite/hematite and carbonates. In the finer fractions clays such as palygorskite, illite and kaolinite can also be important (Alastuey et al., 2005), although there are big differences in clays abundance depending on the source area of the dust. Thus, dust from North and West Sahara contains abundant illite, whereas kaolinite is dominant in dust from the South and Central Sahara (Goudie and Middleton, 2006).

Saharan dust has attracted increasing attention due to the important influences on nutrient dynamics and biogeochemical cycling in both oceanic and terrestrial ecosystems in North Africa and far beyond, due to frequent long-range transport across the Atlantic Ocean, the Mediterranean Sea and the Red Sea, to the Americas, Europe and the Middle East. Atmospheric dust concentrations may also have considerable climatic significance through a range of possible mechanisms, and the frequency of dust events can change substantially in response to climatic changes over several time scales (Goudie and Middleton, 2001). Finally, dust outbreaks may also cause health impacts due to the high levels of PM and to the transport of anthropogenic pollution (Erel et al., 2006) and also to the possible transport of micro-organisms (Polymenakou et al., 2008).

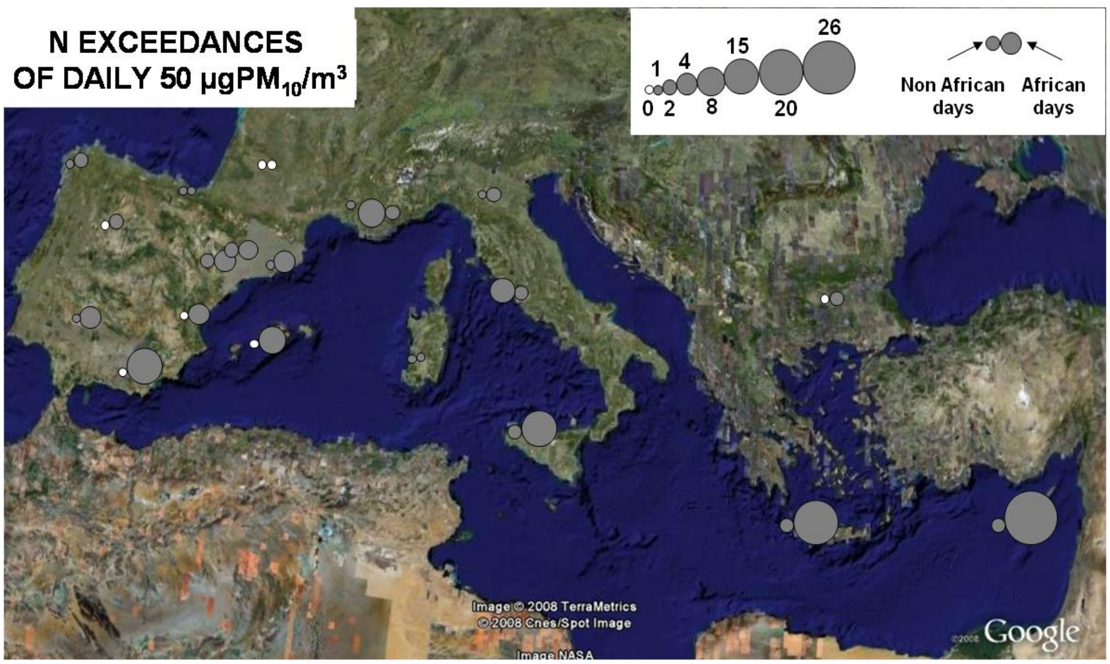

Figure 1. Map of regional background sites in Southern Europe with the number of daily exceedances of the PM_{10} limit value marked for African days (right circle) and non African days (left circle).

Source: Querol et al., 2009

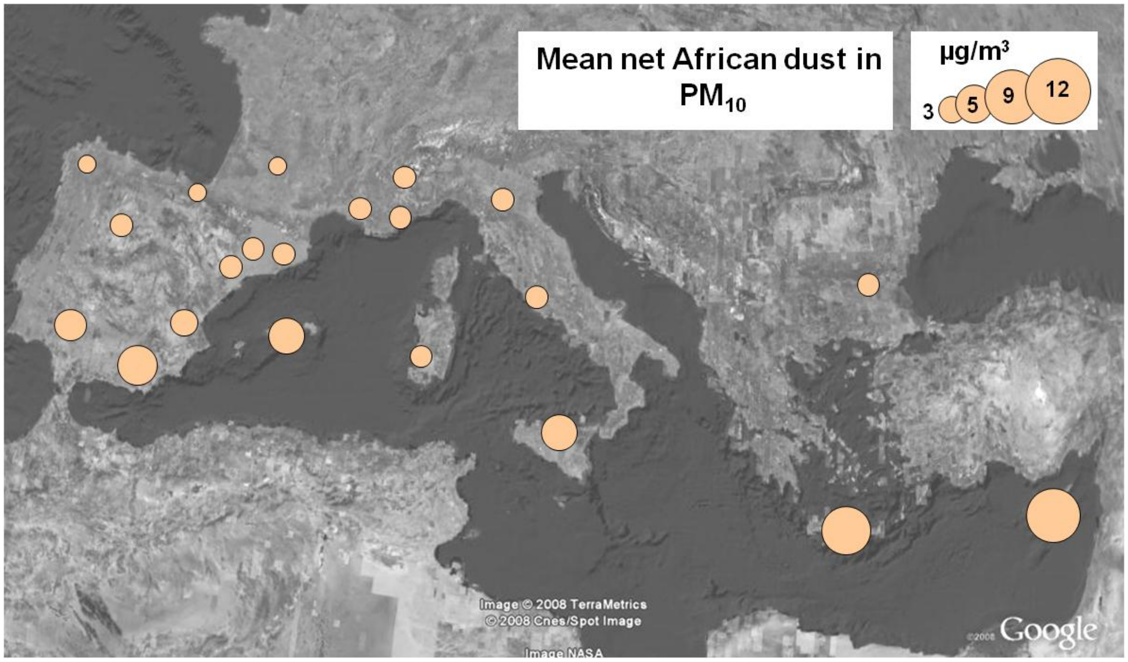

Figure 2. Mass contribution (in µg/m^3) of African dust in PM_{10} for the Mediterranean Basin

Source: Querol et al., 2009

3. Results and discussion

3.1 Methodologies for studying the health effects of African dust

Unlike the chemical composition and transport pattern of dust events, the possible health effects have been rarely studied. In the literature only 12 studies report on the health effects of Sahara dust particles in the region of Europe. All these studies have been conducted in south European countries. The majority of these works are epidemiological studies (Tobias et al., in press; Sajani et al., 2011; Mallone et al., 2011; Samoli et al., 2011a; Jimenez et al 2010; Perez et al., 2008; Middleton et al., 2008) that investigate the association between Sahara dust outbreaks and mortality/morbidity. One study is a toxicological study where the microbial quality of the aerosols over the eastern Mediterranean region during an African storm was examined (Polymenakou et al., 2008), while one study reports on the inhalation dose during dust episodes (Mitsakou et al., 2008). Finally, Dadvand et al. (2011) have studied the impact of Saharan dust episodes on pregnancy complications (preeclampsia and bacteriuria) and outcomes (birth weight and gestational age at delivery), Samoli et al. (2011b) have investigated the pediatric asthma exacerbation caused by air pollution and dust events while Tobias et al. (2011) report on the risk of meningococcal meningitis due to Sahara dust.

Epidemiological study designs have been used to investigate health effects of air pollution. Most contemporary epidemiological studies of particulate matter health effects use either cohort or time-series approaches. Time-series studies assess the effects of short-term changes in air pollution on acute health effects by estimating associations between day-to-day variations in both air pollution and in mortality and morbidity counts within the same geographical area. Thus, the data for daily time-series analysis include daily measures of the number of health events (e.g., daily mortality/morbidity count), concentrations of PM (e.g., 24-h average PM_{10}) and other air pollutants (e.g ozone), and weather variables (e.g., daily temperature) for a given area. Short-term effects from time-series studies are estimated by using regression models where the concentration of PM is included in the model lagged for 0 (current day) to a few days.

Regression models are used in time-series analysis to estimate the increase in risk for a health outcome, such as mortality, associated with a unit increase in ambient air pollution levels on a short-term basis. Frequently used statistical methods for time-series analysis include regression models with smooth functions of time and temperature to adjust for seasonal variations, long-term trends, and temporal changes in temperature that might bias the estimation of the health risk. Statistical concerns for estimating short-term effects from analyses of timeseries data include: (*a*) controlling for observed and unobserved confounding factors, such as season and temperature, that might confound the true association between pollution and health; (*b*) accounting for serial correlation in the residuals that might underestimate statistical uncertainty of the estimated risk; (*c*) selecting the lag of the exposure variable; (*d*) accounting for exposure measurement error; and more in general, (*e*) assessing and reporting uncertainty associated with the choice of statistical model (Dominici et al., 2003, Bell et al., 2004). A number of studies (Dadvand et al., 2011; Samoli et al., 2011a; Samoli et al., 2011b; Jimenez et al., 2010; Middleton et al., 2008) use regression models constructed for days with Saharan dust intrusions and for control days when no dust event was observed. The most common choices for the regression models are the generalized linear model (GLM) with parametric regression splines (e.g. natural cubic splines) and generalized additive models (GAM) with nonparametric splines (e.g. smoothing splines), (Dominici et al., 2003; Bell et al., 2004).

Many studies (Tobias et al., in press; Tobias et al., 2011; Mallone et al., 2011; Sajani et al., 2010; Perez et al., 2008)concerning Sahara dust health effects use case-crossover designs. This design uses the day on which the outcome of interest (mortality) occurs as a case day. Exposure on case days is compared with exposure on days on which the outcome of interest does not occur (control days). The association between PM and mortality is estimated by odds ratios (ORs) for the same day up to several days after exposure using logistic regression models adjusted for several parameters (e.g.: temperature, seasonal trends.

The epidemiological studies concerning Sahara dust health effects include a time-series study on daily mortality/morbidity among a specific age group (above 75 years: Jimenez et al 2010) or for all ages (Samoli et al., 2011a; Sajani et al., 2010; Perez et al., 2008). The causes of mortality examined in these studies are separated as total causes (except accidents), cardiovascular, respiratory and cerebrovascular causes. Only one study exists where the association between daily morbidity and dust storms is examined (Middleton et al., 2008).

Table 1 provides an overview of the studies conducted in Europe that investigate the health effects of Sahara dust particles. Dust episodes were identified by the following methods:

- the high levels of PM_{10} particles (> 100 $\mu g/m^3$) for more than two consecutive days and back trajectories analysis using information obtained from NRL, SKIRON and BSC-DREAM dust maps (Perez et al., 2008)
- by the combination of Lidar observations with operational models and the changes of the ratio PM_{10}/NO_2 (Mallone et al., 2011)
- the hourly number concentration of coarse (diameter>1μm) aerosol particles, considered to be a marker of dust transport events from the Sahara desert. Air mass back-trajectories were calculated using the FLEXTRA model (Sajani et al., 2011)

The daily mean PM (PM_{10}, $PM_{2.5}$, $PM_{10–2.5}$) levels were used as independent variables. Control variables usually included: other ambient co-pollutants, trend, seasonality, influenza epidemics, and autocorrelations between mortality/morbidity series. Estimated effects are reported as percentage increases in risk of death (IR %), and 95% confidence intervals (95% CI) associated with an interquartile range (25th – 75th percentiles - IR) increase in each pollutant.

Tobias et al. (in press), Sajani et al. (2010), Perez et al. (2008) and Mallone et al. (2011) investigated the association of Saharan dust outbreaks and PM concentration with mortality using conditional logistic regression models with adjustment for several variables: temperature, humidity, pressure, flu epidemic weeks, heat waves. In the study of Jimenez et al. (2010) the control variables were: ambient pollutants (chemical, biotic and acoustic); trend; seasonalities; influenza epidemics; and autocorrelations between mortality series. Generalised linear models (GLMs) with Poisson regression were used to quantify the resulting association between the independent and dependent variables. Similarly Samoli et al. (2011a) used Poisson regression models to investigate the effect of desert dust events on mortality using an indicator variable and its interaction with PM concentrations. The variables used were long-term trends and seasonality as well as meteorological variables, temperature, mean daily humidity, wind speed and wind direction, correlation and potential confounding effects from other pollutants, SO_2, NO_2 or O_3 were also included in the model. Middleton et al, 2008 report on the effect of changes in levels of air pollutants on the number of daily admissions in hospitals by means of Poisson regression models. The model controlled for long- and short term trend, temperature and relative humidity. Wind speed, precipitation and barometric pressure were not considered as confounders of the association between air pollutants and hospitalization. Dadvand et al. (2011) used regression models to study the effect of Sahara dust outbreaks on pregnancy complications (preeclampsia and bacteriuria) and outcomes (birth weight and gestational age at delivery).

Table 1. Summary results of all European studies relating Sahara dust events to mortality, morbidity, and pregnancy implications

Reference	**Location**	**Population**	**Outcome**	**Identification of Sahara dust days**	**PM fraction**	**Causes**	**% Risk per 10 μg/m^3 (95% CI) p-value**	**% Risk per 10 μg/m^3 IR% (95% CI)**
							Sahara dust days	**Non-Sahara dust days**
Tobias et al., in press	Madrid, Spain	All ages	Mortality	Back trajectoty analysis	$PM_{2.5}$	TotM	2.9 (-1.1, 6.9) 0.0812	2.6 (0.6, 4.6)
					$PM_{2.5-10}$	TotM	2.8 (0.1, 5.8) 0.016	0.6 (-1.1, 2.4)
Sajani et al., 2011	Emilia-Romagna, Italy, Aug 2002- Dec 2006	All ages	Mortality	PM number concentrations, back trajectory analysis	PM_{10}	TotM	0.0 (-3.5, 3.6) 0.55	0.8 (0.0-1.6)
						CVD	-0.8 (-5.9, 4.6) 0.61	0.3 (-0.9, 1.5)
						RESP	-0.2 (-10.8, 11.5) 0.69	1.6 (-0.9, 1.4)
Mallone et al., 2011*	Rome, Italy, Feb 2001- Dec 2004	Age>35	Mortality	Lidar Observations, PM_{10}/NO_2>0.6	$PM_{2.5}$	TotM	3.2 (-1.1, 7.8) 0.31	0.9 (-1.1, 2.9)
						CAR	1.4 (-5.9, 9.2) 0.92	1.0 (-2.2, 4.3)
						CER	-3.2 (-11.7, 6.1) 0.51	-0.1 (-4.3, 4.3)
						CIRC	-0.9 (-7.0, 5.6) 0.53	1.2 (-1.6, 4.1)
						RESP	8.4 (-12.76,34.5) 0.37	-2.2 (-12.7, 9.7)
					PM_{10}	TotM	3.2 (-0.0, 6.5) 0.91	3.0 (1.3, 4.7)
						CAR	9.6 (3.81, 15.61) 0.02	2.1 (-0.8, 5.0)
						CER	1.7 (-5.05, 8.95) 0.72	3.2 (-1.8, 8.5)
						CIRC	5.9 (1.0, 11.0) 0.13	1.8 (-0.6, 4.3)
						RESP	2.7 (-12.8,20.8) 0.80	5.0 (-2.8, 13.4)
					$PM_{2.5-10}$	TotM	2.1 (-1.1, 5.3) 0.50	3.3 (1.3, 5.4)
						CAR	9.7 (4.3, 15.5) 0.01	0.9 (-2.5, 4.3)
						CER	7.0 (1.2, 13.2) 0.53	4.6 (-0.2, 9.6)
						CIRC	7.9 (3.2, 12.9) 0.04	2.2 (-0.7, 5.3)

						RESP	19.4 (0.3, 42.2) 0.35	8.7 (-4.1, 23.2)
Samoli et al., 2011a	Athens, Greece 2001-2006	All ages	Mortality	Aerosol optical depth, $PM_{10\ remote}/PM_{10\ urban}$> annual median	PM_{10}	TotM CVD[+] RES[+]	-0.1 (-0.6, 0.4) NA 0.2 (-0.4, 0.9) NA 0.2 (-0.5, 2.7) NA	1.0 (0.7, 1.4) 1.4 (1.8, 2.9) 1.5 (0.3, 2.8)
Jimenez et al., 2010	Madrid, Spain Jan 2003-Dec 2005	Age>75	Mortality	Method by Escudero et al.,2007	$PM_{2.5}$	TotM CIRC RES	No statistical significant effects	2.0 (1.0, 4.0) 3.0 (3.0, 4.0) 3.0 (0.0, 6.0)
					PM_{10}	TotM CIRC RESP	2.7 (1.4, 4.1) <0.05 4.0 (1.7, 6.3) <0.05 3.5 (0.9, 6.1) <0.05	No statistical significant effects
Perez et al., 2008	Barcelona, Spain Mar. 2003-Dec. 2004	All ages	Mortality	Back trajectory analysis, $PM_{10\ remote} \geq 0.5 \times PM_{10\ urban}$	$PM_{2.5}$	TotM	5.0 (0.5, 9.7) 0.56	3.5 (1.6, 5.5)
					$PM_{2.5\text{-}10}$	TotM	8.4 (1.5, 15.8) 0.05	1.4 (0.8, 3.4)
Middleton et al., 2008	Nicosia, Cyprus Jan 1995-Dec 2003	All ages	Morbidity	Meteorological observations (visibility), PM_{10} criteria ($PM_{10} \geq 100 \mu g/m^3$)	PM_{10}	MORD	4.8 (0.7, 9.0) NA	5.5 (3.5, 7.6) for the highest PM_{10} levels observed
						CVD-MORD	10.4 (-4.7, 27.9) NA	6.3 (0.0, 15.0) for the highest PM_{10} levels observed
Samoli et al., 2011b	Athens, Greece 2001-2004	Age: 0-14	Morbidity	Back trajectory analysis, $PM_{10\ remote}/PM_{10\ urban}$> annual median value	PM_{10}	PAA	4.1 (0.1, 8.3) 0.41	2.1 (-1.0, 5.2)
Tobias et al., 2011	Barcelona, Spain	All ages	Morbidity	NA	NA	MENG	39.2 (15.2, 68.1) <0.05	NA
Dadvand et al., 2011	Barcelona, Spain, 2003-2005		Pregnancy	PM_{10}, NO_2 trends, back trajectory analysis	PM_{10}	BW‡ GAD‡	-2.1 (-5.8, 1.7) 0.28 0.5 (0.4, 0.6) <0.01	NA NA

CI: Confidence interval
NA: Not available
p-value: p-value of the interaction between PM and the Saharan dust indicator if <0.05 statistical significant model results
Mortality causes: CAR: Cardiac, CER: Cerebrovascular, CVD: Cardiovascular, CIRC: Circulatory, RESP: Respiratory, TotM: Total Mortality
MORD: Morbidity, CVD-MORD: Cardiovascular morbidity,
PAA: pediatric asthma admissions, BW: Birth weight, GAD: gestational age at delivery, MENG: meningococcal meningitis
* Mallone et al., 2011 provide the effect estimate per 12.8 $\mu g/m^3$, 10.8 $\mu g/m^3$ and 19.8 $\mu g/m^3$ for $PM_{2.5}$, $PM_{2.5\text{-}10}$ and PM_{10} respectively
+ among the elderly, age>75
‡ regression coefficients for one episodic day increase for the whole pregnancy

3.2 Health Effects from fine particles

Only four works report on the health effects of the fine fraction of Sahara dust (Tobias et al., in press; Mallone et al., 2011; Jimenez et al., 2010; Perez et al., 2008). These studies produced similar results, the association (if any) of fine particles with total or cause specific mortality was not statistical significant. In Barcelona (Spain) the effects of short-term exposure to $PM_{2.5}$ was not statistical significant (p for interaction= 0.56) during Saharan dust days. A daily increase of 10 $\mu g/m^3$ in $PM_{2.5}$ increased daily mortality by 5.0% (95% CI 0.5–9.7) during Saharan dust days compared with 3.5% (95% CI 1.6–5.5) during non-Saharan dust days (Perez et al., 2008). The study of Jimenez et al., (2010) conducted in

Madrid (Spain) found that the daily mean $PM_{2.5}$ concentrations displayed a significant statistical association with daily mortality for total mortality, circulatory and respiratory causes on non-Saharan dust days, while this association was absent for Saharan dust days. Similarly, a recent study conducted in the same region (Madrid, Spain) report that $PM_{2.5}$ health effects did not vary during Sahara dust days (Tobias et al., in press). In Rome, (Italy) Mallone et al. 2011 found that $PM_{2.5}$ effect estimates during Sahara dust days were positive for natural causes mortality, cardiac and respiratory, but not statistically significant ($p > 0.05$) with p values of the interaction terms greater than 0.15 and always above 0.30.

3.3 Health Effects from coarse particles

All studies concerning health effects caused by coarse particles during dust outbreaks report on PM_{10} or $PM_{2.5-10}$. It should be noted that sometimes $PM_{2.5-10}$ is calculated by subtracting a direct measurement of $PM_{2.5}$ from a direct measurement of PM_{10}. The disadvantage of this is that coarse particle measurement is then affected by two measurement errors rather than one.

Although all studies reach the same conclusion regarding fine particles the results for the coarse fraction are not in agreement. Some of the published studies state that coarse particles during Sahara dust days increase mortality while other studies find no association between mortality and coarse PM.

The analysis of morbidity in Nicosia, Cyprus (Middleton et al., 2008) showed an increased risk (10.4%) of hospitalisation on Saharan dust storm days, particularly due to cardiovascular causes but the magnitude of the effect was comparable to that seen on the quartile of non-desert days with the highest levels of PM_{10} (6.3%). The authors stated that inference from these associations was limited by the small number of dust storm days in the study period. A recent study conducted in Athens, Greece reports that the effect of PM_{10} on mortality during non-desert dust events was higher than the effect identified during the whole studied period and essentially null during dust event days. The analyses indicated that traffic related particles, which prevail on non-desert dust days, have more toxic effects than the ones originating from long-range transport, such as Sahara dust (Samoli et al., 2011a). On the other hand the same research team found an increase of risk on pediatric asthma exacerbation dust Sahara dust episodes (Samoli et al., 2011b). Sajani et al. (2011) in Emilia Romagna, (Italy) found no evidence of an effect modification of dust events on the concentration-response relationship between PM_{10} and daily deaths.

The work of Perez et al. (2008) showed that coarse particles during Sahara dust days significantly increased daily mortality in Barcelona, Spain. A daily increase of 10 $\mu g/m^3$ of $PM_{10-2.5}$ increased daily mortality by 8.4% ($p=0.05$) compared to 1.4% determined for the non-Sahara dust days. The study of Tobias et al. (in press) the used the same methodology with Perez et al. (2008) also reached the conclusion that $PM_{10-2.5}$ health effect was higher during Saharan dust days than during non-Saharan dust days. Similarly, Mallone et al., 2011 found that associations of $PM_{2.5-10}$ with cardiac mortality were stronger on Saharan dust days (9.73%, $p=0.005$) than on non-Sahara dust days (0.86%). In the same study during Sahara dust days PM_{10} concentrations caused an increase of 9.55% of cardiac mortality compared to 2.09% on dust free days, ($p=0.02$). Jimenez et al. (2010) found that daily PM_{10} concentrations in Madrid displayed a significant statistical association with daily mortality for all causes on days with Saharan dust while this association was not in evidence for non-Sahara dust days. These studies concluded that Saharan dust outbreaks may have adverse health effects and pointed out the necessity of further investigation into the role of coarse particles and the mechanism by which Saharan dust increases mortality.

3.4 Relationship between chemical species and health effects

Concerning the potential impact of specific chemical species and human disease in Europe, Perez et al., (2008) studied the chemical composition of particulate matter to explain changes of health effects. They obtained chemical composition of $PM_{2.5}$ and PM_{10} particles including: nonmineral carbon (nmC), total carbon, crustal and marine aerosol elements (sodium and chloride), inorganic secondary components (sulfate, nitrate, and ammonium), metals and trace elements. The chemical composition of $PM_{10-2.5}$ was obtained by subtracting the chemical composition of $PM_{2.5}$ from PM_{10}. Comparison of changes in adjusted mass and chemical concentration during Saharan and non-Saharan dust days was carried out by multivariate linear regression. Figure 3 provides the mass concentration of major species groups during Saharan and non-Saharan dust days. During Saharan dust days, $PM_{2.5}$ was dominated by nonmineral carbon (40% of the particulate matter) and secondary inorganic aerosols (34%), with lesser amounts of crustal elements (23%). In contrast, $PM_{10-2.5}$ was dominated by crustal elements (65%), with lesser amounts of secondary aerosols (18%), marine aerosols (8%), and nonmineral carbon (8%). The chemical composition varied equally in $PM_{2.5}$ and $PM_{10-2.5}$ during Saharan dust days. In addition, metals involved in oxidative stress pathways, such as iron, copper, lead, and zinc were similarly abundant during Saharan dust days and non-Saharan dust days in $PM_{10-2.5}$. The authors concluded that some factor associated with $PM_{10-2.5}$ and transported by Sahara dust such as pesticides or industrial byproducts, though not detected, could be responsible for increased mortality. They also suggest that the biogenic load of coarse particles in Saharan dust is a possible explanation of observed effects. Although coarse particles seem to be more hazardous during Saharan dust days, differences in chemical composition did not explain these observations.

Further work should be conducted regarding the chemical composition of coarse fraction during Sahara dust episodes. The study of Perez et al., (2008) raises concern over possible underestimation of toxicity from coarse particles when they come from desert sources (Sandstorm and Forsberg, 2008). Evidence exist from previous studies that allergenic and inflammatory effects are stronger in coarse particles than in fine particles (Happo et al. 2007, Alexis et al. 2006) while Griffin et al., (2001) detected the presence of bacteria and fungi in Saharan dust particles. The study of Polymenakou et al. (2008) reveals the presence of numerous pathogens at aerosol particles during an intense Sahara dust event in the Eastern Mediterranean.

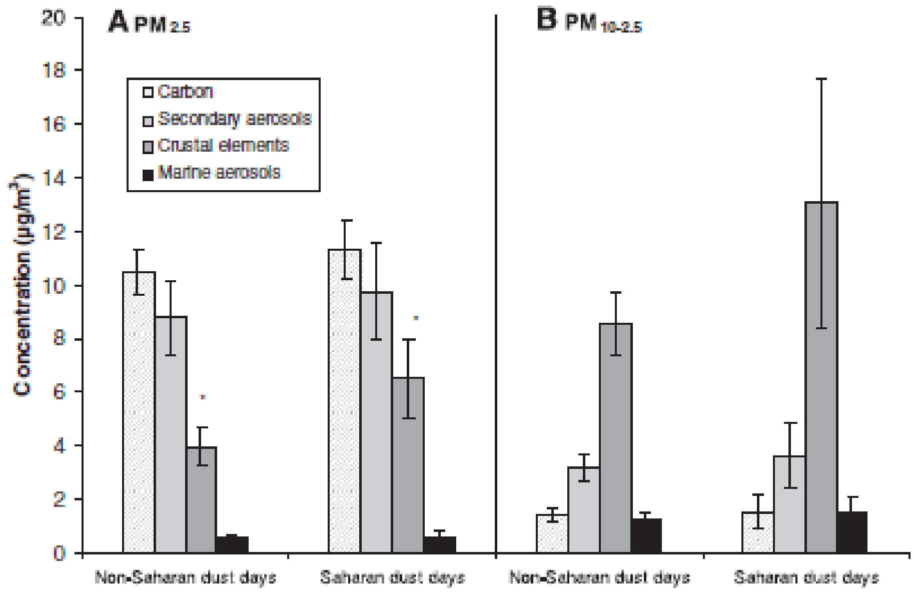

Figure 3. Mean concentrations (with 95% CI) of the major group of elements in $PM_{2.5}$ and $PM_{10\text{-}2.5}$ during non-Saharan dust days (n = 80) and Saharan dust days (n = 9). Asterisk indicates *P* value _0.05 for comparison within each fraction of the mass-adjusted concentrations during Saharan and non-Saharan dust days.

Source: Perez et al., 2008

3.5 Health effects of desert dust worldwide

In relation to the health effects of desert dust in regions other than the European continent several studies report on the association between dust outbreaks and mortality mainly from cardiovascular and respiratory causes. The majority of these studies concern Asia, mostly Taiwan and Korea and Asian desert dust (De Longueville et al., 2010). In Taipei, Taiwan, during Mongolian dust events an increase of 10 ìg m^{-3} in PM_{10} increased total mortality by 0.72% (Chen et al., 2004). Other studies in Asia report on the risk factors of Asian dust in respiratory and cardiovascular diseases (Mu et al., 2010; Cheng et al., 2008; Yoo et al., 2008; Meng and Lu, 2007; Kwon et al. 2002; Park et al., 2005). However, the evidence from these studies was limited because exposure assessments were inadequately described and potential confounders were insufficiently controlled (Hashizume et al., 2010). For the region of sub-Saharan Africa only one study refers to the potential role of natural mineral dust in the respiratory function of children (Glew et al., 2004). In Brisbane, Australia, desert dust events were associated with changes in asthma severity (Rutherford et al., 1999). Concerning Central America previous studies focusing on pediatric asthma accident and emergency admissions in the Caribbean island of Trinidad, show an increase in respiratory health effects in association with Saharan dust days (Monteil 2008; Gyan et al. 2005). However, a subsequent study did not confirm these findings (Prospero et al., 2008).

3.6 Prediction and Mitigation measures

There is growing evidence and scientific consensus that climate change is real. Over the past years, many countries across the European region have experienced increasing numbers of heat-waves, floods and/or droughts (Ternbeth et al., 2007). Moreover, these climate events may add to existing problems of desertification, while also introducing new threats to human health. Specifically, the European continent has large areas of dry lands around 299.7 Mha, susceptible to desertification (UNEP, 1991).

Desertification processes affect between 8-10 % of the total European land from low to high degrees of degradation. The main factors and causes of desertification processes acting in Europe are geomorphology favouring soil erosion processes, alterations of the water balance, overexploitation of water resources, increasing forest fires, etc. The Mediterranean region is particularly sensitive to desertification processes due to its fragile environmental conditions. Steps should be taken to ensure relevant health protection, as climate change and desertification process will probably cause an increase of dust outbreaks. Research should be done on the way to model and predict desertification of the Mediterranean Basin as long as the occurrence of dust storms. Further work is needed on the important questions of monitoring, prediction and forecasting of Sahara dust intrusions. Dust forecasts could be used to inform the public so to reduce health risks. Alert messages and general recommendations to the public and especially the elderly such as to reduce outdoor activities during dust storms could improve public health.

Another issue to consider is that sedimentation of African dust during dust outbreaks may increase resuspension during a number of days after the episode. These resuspension contributions may considerably enhance PM levels for a longer period than the duration of the dust intrusion. To abate the resuspension of deposited dust after intensive African dust outbreaks, mitigation measures could be adapted by the national authorities of countries suffering by frequent episodes. Street sweeping and cleaning could be efficient in reducing Sahara dust particles available for resuspension. Recent studies provide evidence that these methods reduce resuspension from paved road surfaces (Karanasiou et al., 2011; Amato et al., 2010).

Conclusions

In Europe the possible health effects of dust outbreaks have been rarely studied. The review of the literature shows that the association of fine particles with total or cause specific daily mortality is not significant during Saharan dust intrusions. However, regarding coarse particles PM_{10} or $PM_{2.5-10}$ an explicit answer cannot be given. Some of the published studies state that coarse particle fraction increase mortality during Sahara dust days while other studies find no association between mortality and coarse PM. The reasons for this discrepancy between the published studies might lie in:

- The different size fraction studied (PM_{10} or $PM_{2.5-10}$) and the different way to determine coarse concentration, eg: $PM_{2.5-10}$ is calculated by subtracting a direct measurement of $PM_{2.5}$ from a direct measurement of PM_{10}. The disadvantage of this is that coarse particle measurement is then affected by two measurement errors rather than one. Studies that report on $PM_{2.5-10}$ (Tobías et al., in press; Mallone et al., 2011; Perez et al., 2008) are in agreement, a strong association was found between concentration levels and daily mortality while studies examining PM_{10} (Samoli et al., 2011a; Sajani et al., 2011; Middleton et al., 2008) produce different results, the impact of Sahara dust on daily mortality was not significant. On the other hand Jimenez et al. 2010 found that PM_{10} concentrations displayed a significant statistical association with daily mortality on days with Saharan dust while this association was not in evidence for non-Sahara dust days.
- The different time periods studied, e.g: heat waves could influence the analysis results so they should be excluded from the databases
- The different studied areas. As environmental conditions are often not evenly distributed over the years, the episodic nature of dust events makes them difficult to study. Epidemiological studies require sufficient statistical power to detect marginally significant effects while the low frequency of Saharan dust days prevent analysis of cause-specific mortality. As the occurrence

and intensity of Sahara dust intrusions is higher in the Eastern Mediterranean Basin rather than in the Western Mediterranean Basin the statistical power of epidemiological studies conducted in these regions is probably different. However, two studies (Mallone et al. 2011 and Sajani et al. 2011) both conducted in Italy reached different results.

- The different methodologies used for the definition of episodic days that include combinations of back trajectories analysis, PM_{10} concentration levels, lidar observations and PM_{10}/NO_2 values. Researchers should conclude to a common protocol for the definition of Sahara dust episodes to produce comparable results.

The main conclusion of this review is that the health impact of Saharan dust outbreaks needs to be further explored, especially in Southern European areas, the most impacted by these episodes using comparable methodologies. Given that some evidence exists for the health risks of coarse particles, $PM_{2.5\text{-}10}$ during Sahara dust events, future studies should focus on the chemical characterization of the coarse particle mode during these episodes. The toxic effects of coarse particles when they originate from desert sources should be further investigated.

The outcome of this paper may be considered to establish the objectives and strategies of the new European 2013 directive on atmospheric particle levels. The Sahara dust outbreaks, which are beyond control from the Member States, mostly affect Mediterranean countries. An implication for public policy in Europe is that to protect public health, anthropogenic sources of particulate pollution need to be more rigorously controlled in areas highly impacted by Saharan dust (Perez and Kunzli, 2011).

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