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REVIEW

Desert dust impacts on human health: an alarming worldwide reality and a need for studies in West Africa

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Abstract High desert dust concentrations raise concerns about adverse health effects on human populations. Based on a systematic literature review, this paper aims to learn more about the relationship between desert dust and human health in the world and to analyse the place of West Africa as a study area of interest. Papers focussing on the potential relationship between dust and health and showing quantitative analyses, published between January 1999 and September 2011, were identified using the ISI Web of Knowledge database (N=50). A number of adverse health effects, including respiratory, cardiovascular and cardiopulmonary diseases, are associated with dust. This survey highlights obvious dust impacts on human health independently of the study area, health outcomes and method. Moreover, it reveals an imbalance between the areas most exposed to dust and the areas most studied in terms of health effects. None of these studies has been conducted in West Africa, despite the proximity of the Sahara, which produces about half of the yearly global mineral dust. In view of the alarming results in many parts of the world (Asia, Europe, America), this paper concludes by stressing the importance of carrying out impact studies of Saharan dust in West Africa, where dust events are more frequent and intense than anywhere else.

Keywords Desert dust · PM_{10} · Health · West Africa

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Introduction

In recent decades, there has been a considerable increase in concerns about the impact of the natural environment on human health. Smith et al. (1999) estimated that 25–33 % of the global burden of disease can be attributed to environmental risk factors. Many of the papers published to date that provide information on health-related particulate matter (PM) research have focussed on the impact of anthropogenically generated PM (such as PM generated by combustion engines) (Bousquet et al. 2003; Bruce et al. 2000; Ezzati 2005; Romieu et al. 2002) while relatively little work has looked at the impact of naturally generated PM (such as PM emanating from dust storms). Winds from the nine principal desert sources transport large amounts of dust around the world (Prospero et al. 2002; Tanaka and Chiba 2006). Overall, studies estimate that the global dust emission varies by a factor of slightly more than two, although extreme values from 1,018 Tg year^{-1} (Miller et al. 2004) to 3,000 Tg year^{-1} (Tegen and Fung 1994) have been established over the last two decades (Engelstaedter et al. 2006). Estimates of the contribution of the different source areas also vary by study and are more difficult to make, especially as each source area follows a distinct seasonal cycle (Engelstaedter and

Washington 2007). However, studies addressing these problems all agree that North Africa is the main source area (over 50 %) (see, e.g. Ginoux et al. 2004; Washington et al. 2003). Regions of the world in the path of dust-laden wind record increased ambient air dust concentrations that are temporally associated with deteriorations in air quality and the strong possibility of negative impacts on human health (Engelstaedter et al. 2006; Kellogg et al. 2004; Ozer et al. 2005). Generally speaking, a distinction is made between particles smaller than 10 µm in diameter (PM_{10}, *thoracic* particles that can penetrate into the lower respiratory system), particles smaller than 2.5 µm ($PM_{2.5}$, *respirable* particles that can penetrate into the gas-exchange region of the lung), and ultrafine particles smaller than 100 nm that contribute little to particle mass but that are most abundant in terms of numbers and offer a very large surface area, with increasing degrees of lung penetration (Brunekreef and Holgate 2002). Thus, coarse particles are more likely to be deposited in the bronchial passages and thereby affect respiratory conditions such as asthma, chronic obstructive pulmonary disease (COPD), and pneumonia. In contrast, fine particles seem more likely to reach the alveoli and lead to cardiovascular events (Sandstrom and Forsberg 2008).

The objective of this paper was to review the impact of desert dust on human health based on results published in international scientific journals since January 1999. The ultimate aim was to investigate the need to undertake such studies in West Africa, near the Sahara, the most important global dust source (e.g. Engelstaedter et al. 2006; Washington et al. 2003). Due to the large quantity of PM emanating from this source (more than 50 % of the total emitted into the atmosphere), the potential risk to health is higher for populations in West Africa.

Data sources and methods

A systematic review of the literature was undertaken to identify relevant studies investigating the impact of desert dust on human health, published between January 1999 and September 2011. The ISI Web of Knowledge database, the premier research platform for information in the science, was queried using ‘Health’, ‘Mortality’, ‘Morbidity’, ‘Respiratory’, ‘Asthma’ or ‘Cardiovascular’ AND 'dust storm', 'sand storm', 'African dust', 'Saharan dust', ‘Asian dust’, ‘Gobi dust’, ‘Yellow dust’ or 'dust events', without any restrictions. Other specific databases were queried with the same search-terms (PubMed, Google Scholar).

All papers returned by the search (430) were evaluated. Only studies with a quantitative analysis element were evaluated further. Studies of anthropogenically generated dust, those of animal health or highly specialised articles (e.g. on the implications of microorganisms in clouds of desert dust) were excluded. Despite the fact that the occurrence of meningitis has been associated with desert dust events (Sultan et al. 2005; Thomson et al. 2006), unexpectedly, no studies on meningitis were returned by the query. A total of 50 individual relevant articles met our inclusion/exclusion criteria (N=50).

A preliminary qualitative investigation of the 50 articles allowed us to summarize each study by identifying various parameters. For each paper, we determined the period, study area, health outcomes investigated, target population, data source, method of data analysis, dust origin (Asia, Sahara, other), dust event definition and the main findings (Table 1). Articles were grouped in four categories according to the presence/absence of statistically significant/not significant desert dust impacts on human health in the results.

In an effort to relate the findings to a West African setting in a meaningful way, pollution levels associated with desert dust found in the studies with a significant dust-health relation were compared with those observed in West Africa, based on PM_{10} aerosol mass concentration data [$\mu g\ m^{-3}$] recently recorded (2006–2007) in a rural Sahelian station located at Banizoumbou (Niger). These data were collected in the frame of the international African Monsoon Multidisciplinary Analysis (AMMA) program at three stations comprising the so-called "Sahelian Dust Transect".

Results and discussion

The content of the 50 papers returned by the search is analysed and discussed in the successive sections below. In the first section, Table 1 highlights commonalities and differences in the studies in terms of methods used and health outcomes. Once studies were sorted according to the type of relationship between dust and health (see Data sources and methods), we looked at potential associations with publication date and dust origin, respectively (see the following two sections). The next section goes deeper into dust event definition and shows the links with health effects. Finally, in the light of the previous discussions, the last section is given over to explaining what it is known so far on how these findings can be associated with field data from West Africa.

Analysis of published studies of impact of desert dust on human health

Of the 50 articles included, 6 and 31were published in the first 5 years (1999–2003) and last 5 years (2007–2011) of the study period, respectively, indicating that, in recent times, there has been increasing interest in the impact of PM on human health. In general, these papers investigated changes in morbidity or mortality before, during and after dust events or compared health effects on populations (at risk or not) between days with dust events and control days.

Table 1 Published studies on desert dust impact on human health. *IHD* Ischaemic heart disease, *CVD* cerebrovascular disease, *COPD* chronic obstructive pulmonary disease, *PEFR* peak expiratory flow rate, *CHF* congestive heart failure, *SDD* Saharan dust day, *ADE* Asian dust event(s), *ED* emergency department, *OR* odds ratio, *LIDAR* light detection and ranging, *RR* relative risk, *CI* confidence interval, *AVI* aerosol vapour index, *TSP* total suspended particulate, *PM* particulate matter

ID	Reference	Date, location	Health outcomes, target population, data source	Method	Dust origin	Dust event definition	Main findings
Cat. 1: Studies reporting a significant relationship between dust and health							
1	Chan et al. 2008	1995–2002 Taipei, Taiwan	Daily emergency visits for cardiovascular diseases, IHD, CVD and COPD. Data from the National Taiwan University Hospital	Two-tail paired t-test Poisson regression model	Asia	Daily PM_{10} concentrations above 100 μg m^{-3}	Emergency visits for IHD, CVD, and COPD during high ADE are increased by 0.7 case (35 %), 0.7 case (20 %), and 0.9 case (20 %) per event, respectively
2	Cheng et al. 2008	1996–2001 Taipei, Taiwan	Daily hospital admissions for cases with principal diagnosis of pneumonia. Data from the National Health Insurance Program	Poisson regression models	Asia	Hourly PM_{10} concentration exceeded the air quality standard (125 μg m^{-3}) lasted for at least 3 h. The average PM_{10} level for the index days was 111.7 μg m^{-3} vs 55 μg m^{-3} for the comparison days	Statistically significant association between ADE and daily pneumonia admissions 1 day after the event
3	Gdalevich et al. 2009	2006–2008 Israël	The number of ED visits for acute cardio-respiratory conditions at a regional medical center	Paired t-test	Sahara	Use of continuous air quality monitoring carried out by the Israel Ministry of Environmental Protection	Mean cardio-respiratory ED patient load on SSDs was 32.67±11.39 visits, compared to a mean of 29.07±5.33 on matched control days (P=0.04). This represents a relative increase of 12.4 % over the expected patient load
4	Gyan et al. 2005	May 2001–May 2002 Island of Trinidad Caribbean	Patients aged 15 years and under who attended the Paediatric Priority Care Facility for asthma of the Wendy Fitzwilliam Children's Hospital	Poisson regression models	Sahara	A reduction in visibility equal to or less than 15 km (+ reddish-brown colour)	Association between increased paediatric asthma admissions and increased Saharan dust cover. A deterioration of visibility due to Saharan dust cover increases a daily admission rate of 7.8 patients to 9.25
5	Hwang et al. 2008	Spring 2002 Seoul, Korea	671 emergency department visits due to atopic asthma. Data from the National Emergency Department Information System database in Seoul	Generalized additive model analysis	Asia	During the episode in 2002, mean daily PM_{10} concentration in Seoul exceeded 600 μg m^{-3}	Rate of ED visits increases 9.4 % for atopic asthma and 15.2 % for visits of persons aged 65 years and older. ADE are associated with risk of emergency department visits due to atopic asthma
6	Jiménez et al. 2010	2003–2005 Madrid, Spain	Daily mortality due to: all organic causes except accidents; circulatory causes; and respiratory causes provided by the Madrid Regional Inland Revenue Department	Poisson regression model	Sahara	According to data from the Directorate-General for Environmental Quality & Assessment at the Ministry for the Environment and Rural & Marine Habitats. The average PM_{10} level for the index days was 47.5 μg m^{-3} vs 31.2 μg m^{-3} for the comparison days	On SDDs, a significant statistical association was detected between PM_{10} and mortality for all three causes analysed

Table 1 (continued)

ID	Reference	Date, location	Health outcomes, target population, data source	Method	Dust origin	Dust event definition	Main findings
7	Johnston et al. 2011	1994–2007 Sydney, Australia	Mortality data (non-accidental, cardiovascular and respiratory mortality) provided by the Australian Bureau of Statistics	Time-stratified case-crossover design with conditional logistic regression	Other	Days for which the 24 h city-wide concentration of PM_{10} exceeded the 99th percentile	Dust events associated with a 15 % increase in non-accidental mortality at a lag of 3 days, OR (95%CI) 1.16 (95%CI: 1.03–1.30)
8	Kanatani et al. 2010	February–April, in 2005–2009 Toyama, Japan	620 hospitalisations of children ages 1–15 years for asthma exacerbation in eight principal hospitals in Toyama	Conditional logistic regression	Asia	Daily mineral-dust concentration above 0.1 mg m^{-3}	Statistically significant association between asthma hospitalisation and a heavy dust event
9	Lee et al. 2007	2000-2004 Seoul, South Korea	The daily counts of non-accidental deaths. Data supplied by the National Statistical Office, Republic of Korea	Time-series analysis	Asia	Mean daily PM_{10} concentration: 188.5 μg m^{-3} (Asian dust days) vs 65.8 μg m^{-3} (days without Asian dust)	Effect sizes of air pollution on daily death rates in the model without ADE were larger than those in the model with ADE, and were statistically significant
10	Lee et al. 2008	June 1999–December 2003 7 metropolitan areas, Korea	The counts of daily admissions for asthma and stroke. Data from the National Health Insurance Program	Poisson regression model	Asia	Mean daily PM_{10} concentration on dust days (84.0 μg m^{-3}) was higher than that on comparison days (56.3 μg m^{-3})	ADE increased admission for asthma and stroke
11	Lopez-Villarrubia et al. 2010	2000–2004 Two Canary Island Cities	Daily death (all-cause, heart and respiratory diseases) reports from the Mortality Register of the Canary Islands Regional Authority	Generalized additive Poisson models, lagged effects up to 5 days	Sahara	Air pollution data were obtained from the Air Quality Network	$PM_{2.5}$ clearly associated with heart disease mortality and $PM_{10-2.5}$ with respiratory mortality
12	Mallone et al. 2011	2001–2004 Rome, Italy	80,423 residents≥35 years of age who died within the city from natural causes. Data were obtained from the Regional Register of Causes of Deaths	Generalized additive model procedure	Sahara	SDDs defined by combining LIDAR observations and analyses from operational models	Evidence of effects of $PM_{2.5–10}$ and PM_{10} on natural and cause-specific mortality, with stronger estimated effects on cardiac mortality during Saharan dust outbreaks
13	Maté et al. 2010	2003–2005 Madrid, Spain	Daily mortality due to diseases of the circulatory system in the city of Madrid during the study period. Data furnished by the Madrid Regional Revenue Authority	Poisson regression models	Sahara		Linear relationship observed between $PM_{2.5}$ levels and mortality due to diseases of the circulatory system. For every increase of 10 μg m^{-3} in daily mean $PM_{2.5}$ concentration, for overall circulatory mortality, associations were established at lags 2 and 6, with RR of 1.022 (1.005–1.039) and 1.025 (1.007–1.043), respectively
14	Meng and Lu 2007	1994–2003 Minqin, China	Total daily hospitalisations for respiratory and cardiovascular diseases. The cases due to accidents or postoperative infection and admissions of people who did not live in Minqin were excluded. Data from two hospitals responsible for most (about 94.8 %) admissions in Minqin	Generalised additive Poisson regressions	Asia	Daily PM_{10} concentration above 300 μg m^{-3}	ADE with a lag of 3 days were significantly associated with total respiratory hospitalisation for males and females

Table 1 (continued)

ID	Reference	Date, location	Health outcomes, target population, data source	Method	Dust origin	Dust event definition	Main findings
15	Middleton et al. 2008	January 1995–December 2004 Nicosia, Cyprus	Cardiovascular and respiratory admissions. Data from two public hospitals in Nicosia. Daily volume of all-cause admissions in the same period was obtained from the Cyprus Statistical Services	Poisson regression models	Sahara	Days with at least 1 hourly PM_{10} concentration higher than 150 μg m^{-3} recorded at Nicosia Central or higher than 100 μg m^{-3} at the rural station	+0.9 % all-causes and +1.2 % cardio-vascular admissions per 10 μg m^{-3} PM_{10}; +4.8 % all-causes and +10.4 % cardiovascular admissions on dust storm days
16	Monteil 2008	March 2003 Trinidad, Caribbean	Clinical paediatric asthma admissions. Several data sources (primary care facilities and hospital)	Poisson regression model	Sahara	Daily PM_{10} concentrations above 85 μg m^{-3}	Significant increase in the number of paediatric admissions for up to 7 days from the peak of dust cover
17	Park et al. 2005	March 2002–June 2002 Incheon, Korea	PEFR and respiratory symptoms of asthmatics. Residents of Incheon between the ages of 16 and 75 years, who had been diagnosed with bronchial asthma. Data from the Gachon Medical Center, Incheon	The general additive model approach with Poisson log-linear regression	Asia	Mean daily PM_{10} concentration on dust days was 188.5 +/− 163 μg m^{-3} (vs 60.0 +/− 19.9 μg m^{-3} ($P<0.05$) on control days), with one recorded peak level of 505 μg m^{-3}	Evidence that ADE impact the respiratory symptoms of subjects with bronchial asthma, and ambient air pollution, particularly elevated PM_{10}, might be one of the aggravating factors
18	Perez et al. 2008	March 2003–December 2004 Barcelona, Spain	Deaths from external causes (including injury, poisoning, and accidents) were not included. Data from the Barcelona mortality registry (24,850 deaths)	Conditional logistic regression	Sahara	PM_{10} concentration at a reference remote rural monitoring site reached at least 50 % of the PM_{10} concentration at the urban sampling site in Barcelona	+8.4 % daily mortality per 10 μg m^{-3} $PM_{10-2.5}$ during SDDs
19	Samoli et al. 2011a	2001–2004 Athens, Greece	Daily time-series data provided by the children's hospitals. All children admitted with the diagnosis of "asthma" "asthmatic bronchitis" or "wheezy bronchitis" aged 0–14 years, living in the greater Athens area were included	Poisson regression models	Sahara	Dust days using back-trajectory analysis in combination with a data driven criterion, based on high particle concentrations pro-vided by the fixed monitoring sites	A 10 μg m^{-3} increase in PM10 was associated with a 2.54 % increase (95%CI): 0.06 %, 5.08 %) in the number of paediatric asthma hospital admissions. Statistically significant PM_{10} effects were higher during winter and during desert dust days
20	Yoo et al. 2008	Spring, 2004 Seoul, South Korea	A group of 52 children with mild asthma were recruited. Data from the allergy clinic at Seoul National University Children's Hospital	Kruskall-Wallis test / Pearson correlation test / paired t-test	Asia	Daily information provided by the Korea Meteorological Administration from a station located in central Seoul	Significantly higher frequency of respiratory symptoms during the Asian dust days than during control day
21	Zauli Sajani et al. 2011	August 2002-–December 2006 Emilia-Romagna, Italy	Residents in the six main cities of the central-western part of the Emilia-Romagna region who died during the study period	Case-crossover design with conditional logistic regression	Sahara	Two SDD definitions were used: (1) all SDD regardless of the intensity of the transport phenomenon. (2) a subset of 'strong' SDDs characterised by coarse particle number concentrations higher than 0.25 particles/cm^3, i.e. the 90th percentile of coarse particle distribution	Evidence of increased respiratory mortality for people aged 75 or older on SDD. Respiratory mortality increased by 22.0 % (95 % CI 4.0 % to 43.1 %) on the SDD in the whole year model and by 33.9 % (8.4 % to 65.4 %) in the hot season model. Effects attenuated for natural and cardiovascular mortality with ORs of 1.042 (95 % CI 0.992 to 1.095) and 1.043 (95 % CI 0.969 to 1.122), respectively

Table 1 (continued)

ID	Reference	Date, location	Health outcomes, target population, data source	Method	Dust origin	Dust event definition	Main findings
Cat. 2: Studies reporting a non-significant relationship between dust and health							
22	Chang et al. 2006	1997–2001 Taipei, Taiwan	Daily clinic visits in which the principal diagnosis was allergic rhinitis. Data from the National Health Insurance Program	Poisson regression models	Asia	Hourly PM_{10} concentration observed exceeded the air quality standard (125 μg m^{-3}) and lasted for at least 3 h. The average PM_{10} level for the index days was 110 μg m^{-3} vs 61.7 μg m^{-3} for the comparison days	The effects of dust storms on clinic visits for allergic rhinitis were prominent 2 days after the event (19 %). However, the association was not statistically significant
23	Chen and Yang 2005	1996–2001 Taipei, Taiwan	Daily counts of hospital admissions for CVD. Data from National Health Insurance Program	Tests of Student	Asia	Average PM_{10} level for the index days was 111.7 μg m^{-3}. It is 56.3 μg m^{-3} higher than for the comparison days	Dust storms on CVD were prominent 1 day after the event (3.65 % increase). However, the association was not statistically significant
24	Chen et al. 2004	1995–2000 Taipei, Taiwan	Cases of daily mortality were divided into two groups: diseases of the respiratory system and diseases of the circulatory systems. Deaths due to accidents and occurring outside of the city were excluded. Data from Department of Health of Taiwan	Tests of Student	Asia	The average PM_{10} level for the index days was 125.9 μg m^{-3}, which was 68.1 μg m^{-3} higher than the average for the comparison days	Dust storms increase risk of 7.66 % for respiratory disease 1 day after the event, 4.92 % for total deaths 2 days following the event and 2.59 % for circulatory diseases 2 days following the event. None of these effects were statistically significant
25	Chiu et al. 2008	1996–2001 Taipei, Taiwan	Possible inadequate sample size of COPD admissions on ADS events days. Data from the National Health Insurance Program	Poisson regression	Asia	The average PM_{10} level for the index days was 111.7 μg m^{-3}. It is 56.3 μg m^{-3} higher than the average for the comparison days	The effects of dust storms on hospital admissions for COPD were prominent 3 days after the event. However, the association was not statistically significant
26	Rutherford et al. 1999	1992–1994 Brisbane, Australia	33 asthmatics (1992); 57 asthmatics (1993); 76 asthmatics (1994). Data collected as part of ongoing studies examining the relationships between asthma and air pollution in Brisbane	Paired two-tailed t-tests	Other	PM_{10} and TSP levels and their ratios for these events are higher than for the other events	Dust events may be associated with changes in asthma severity, particularly if these dust events elevate particulate concentrations and are dominated by fine particles
27	Watanabe et al. 2011	April–May 2007 Western Japan	98 patients with adult asthma by telephone survey	Mann–Whitney nonparametric test, Chi^2 test and multivariate logistic regression analysis	Asia	The Japan Meteorological Agency and Ministry of the Environment define individual ADS events based on local data	ADS aggravated lower respiratory symptoms in adult patients with asthma, but this influence was mild
28	Yang et al. 2005b	1996–2001 Taipei, Taiwan	Daily admissions for cases in which the principal diagnosis was asthma. Possible inadequate sample size of asthma admissions on ADE. Data from the National Health Insurance Program	Poisson regression model	Asia	Hourly PM_{10} concentration observed exceeded the air quality standard (125 μg m^{-3}) and lasted for at least 3 h. The average PM_{10} level for the index days was 111.7 μg m^{-3}. It is 56.3 μg m^{-3} higher than the average for the comparison days	The effects of dust storms on asthma admissions were prominent 2 days after the ADE (8 %). However, the association was not statistically significant

Table 1 (continued)

ID	Reference	Date, location	Health outcomes, target population, data source	Method	Dust origin	Dust event definition	Main findings
29	Yang 2006	1997–2001 Taipei, Taiwan	Daily data on clinic visits in which the principal diagnosis was conjunctivitis. Data from the National Health Insurance Program	Poisson regression	Asia	Mean daily PM_{10} concentration: 110.37 μg m^{-3} (Asian dust days) vs 61.73 μg m^{-3} (days without Asian dust)	The effects of dust storms on clinic visits for conjunctivitis were prominent 4 days after the event. However, the association was not statistically significant
30	Yang et al. 2009	1996–2001 Tapei, Taiwan	Hospital admissions for CHF. Possible inadequate sample size. Data from the National Health Insurance Program		Asia	Hourly PM_{10} concentration observed exceeded the air quality standard (125 μg m^{-3}) and lasted for at least 3 h. The average PM_{10} level for the index days was 111.7 μg m^{-3}. It is 56.3 μg m^{-3} higher than the average for the comparison days	The effects of dust storms on hospital admissions for CHF were prominent 1 day after the event (relative risk= 1.114; 95 % confidence interval= 0.993–1.250). However, the association was not statistically significant
Cat. 3: Studies concluding with no association between dust and health							
31	Barnett et al. 2011	1 January to 31 October 2009 Brisbane, Australia	The health data were the emergency admissions to the Prince Charles Hospital	Poisson regression model	Other	References: Australian National Environment Protection Measures for Ambient Air Quality standards of 50 μg m^{-3} for PM_{10} and 25 μg m^{-3} for $PM_{2.5}$	The health effects of the storm could not be detected using particulate matter levels. There was no significant change in the characteristics of admissions during the storm; specifically, there was no increase in respiratory admissions
32	Bennett et al. 2006	1997–1999 British Columbia, Canada	Hospital admissions selected if the primary diagnosis was 'respiratory' or 'cardiac'. Data from the British Columbia Linked Health Database administered by the Centre for Health Services and Policy Research	Time-series analyses	Asia	For the 1998 event, hourly PM_{10} concentrations peaked at 120 μg m^{-3}, while for the 1997 May event, concentrations were in the 40–50 μg m^{-3} range	This Gobi dust event was not associated with an excess of hospitalisations
33	Goto et al. 2010	1998-2007 Nagasaki, Japan	Annual data of the death toll of asthma disease according to city and town organised by Nagasaki prefecture and the categorical data of death tolls and death rates according to simple classification of cause of death (for the population of 100,000 people) summarised by the annual total of the monthly report of vital statistics published by the Ministry of Health, Labour and Welfare	Spearman's rank correlation	Asia	Use of AVI from NOAA/AVHRR data to comprehend the amount of incoming yellow dust	No significant correlation between the annual average amount of incoming yellow dust obtained from satellite data and the annual average mortality rate from asthma
34	Hong et al. 2010	13 May–15 June, 2007 Seoul, Korea	110 school children of 9 years old from an elementary school in Seoul. Information was collected from questionnaire	Linear mixed-effects model	Asia	Asian dust storm event day in Seoul when PM_{10} concentrations is > 130 μg m^{-3}	Ambient concentrations of $PM_{2.5}$ and PM_{10} were not significantly associated with PEFR in school children except asthmatics during the study period ($P>0.05$)

Table 1 (continued)

ID	Reference	Date, location	Health outcomes, target population, data source	Method	Dust origin	Dust event definition	Main findings
35	Hwang et al. 2003	Spring period of 2000 through 2002 Seoul, Korea	Daily hospital admissions for respiratory and cardiovascular disease. Data from the National Health Insurance database in Seoul	Generalised linear model with a log-link and a Poisson distribution	Asia	During the episode in 2002, daily average of PM_{10} in Seoul exceeded 600 μg m^{-3}	Estimated relative risk of hospitalisation for respiratory disease for the ADE was 1.00 and the risk for cardiovascular disease was 0.99. Results indicate little effect of Asian dust events on the hospitalisation for respiratory and cardiovascular disease
36	Hwang et al. 2004b	Spring period of 2000 through 2002 Seoul, Korea	Emergency department visits due to respiratory disease (163,260) and to cardiovascular disease (50,032). Data from the National Health Insurance database in Seoul	Case-crossover analysis	Asia	During the episode in 2002, daily average of PM_{10} in Seoul exceeded 600 μg m^{-3}	Results showed OR of 0.96 in respiratory disease and 0.94 in cardiovascular disease with ADE exposure. OR had decreased pattern with the same day through 4-day lag, but OR of 0.99 in respiratory disease and 1.14 in cardiovascular disease with 5-day lag
37	Lai and Cheng 2008	2000–2004 Taipei, Taiwan	All respiratory admissions were used, including the readmission of patients. Data from Taiwan Bureau of National Health Insurance	Spatial analysis in GIS	Asia	When the PM_{10} concentration in four stations located in northern Taiwan increase from the long term average concentration of 50 μg m^{-3} to 100 μg m^{-3}	PM_{10} and O_3 concentrations increased significantly on the first 2 days of ADE. The areas showing significant increases in respiratory admissions did not match well with the areas with the most significant air quality deterioration
38	Prospero et al. 2008	1996–1997 Caribbean	Daily attendance asthma of paediatric patients (7,158 cases in 1996 and 8,584 in 1997). Data from the asthma clinic in Barbados	Mann–Whitney rank-sum test, two-tailed	Sahara	Peaks in dust concentration, some approaching or exceeding 100 μg m^{-3}	No obvious relationship although there may be more subtle linkages between dust and asthma
39	Samoli et al. 2011b	2001–2006 Athens, Greece	The daily counts of all-cause mortality excluding deaths from external causes, cardiovascular mortality and respiratory mortality obtained from the Greek National Statistical Service	Poisson regression model	Sahara	The PM_{10} median concentration from this monitoring station was 66.8 μg m^{-3} during desert dust events and 52.0 μg m^{-3} for the rest of the days	The particles' effects were significantly higher during non-desert dust days
40	Schwartz et al. 1999	1989–1995 Spokane, WA	Daily counts of deaths from non-external causes. Data from death certificate records filed with the State Department of Health	Poisson regression	Other	The daily mean PM_{10} concentration during dust storms was 263 μg m^{-3} (vs 42 μg m^{-3} during control days)	There was little evidence of any risk on the episode days. It is concluded that coarse particles from windblown dust are not associated with mortality risk
41	Wiggs et al. 2003	May 2000–April 2001 Karakalpakstan, Uzbek Republic	Respiratory health. A total target population of 1,644 children. Original data from questionnaires	Spatio-temporal analysis	Other	Based on total dust deposition rate and PM_{10} concentrations	Children living in the north of the country, where aeolian dust deposition rates are greater, show a lower frequency of respiratory problems

Table 1 (continued)

ID	Reference	Date, location	Health outcomes, target population, data source	Method	Dust origin	Dust event definition	Main findings
Cat. 4: Studies presenting mixed results depending on type of diseases or pollutants							
42	Bell et al. 2008	1995–2002 Taipei, Taiwan	Hospital admissions at National Taiwan University Hospital for two classes of cardiovascular event (IHD, CVD) and for two classes of event causes (asthma, pneumonia). Data from the National Health Insurance Program	Time-series analyses	Asia	Daily PM_{10} concentrations > 115 μg m^{-3} in Tapei city and > 100 μg m^{-3} at the Yangmin background monitoring station	Asthma (associations with PM_{10}), pneumonia (no statistically significant association), CVD (associations with PM_{10} and CO at 3 day lags), IHD (associations with presence of sandstorms)
43	Gwack et al. 2005	53 successive days Seoul, Korea	PEFR in children with bronchial asthma and in healthy children. Data from the Gachon Medical Center, Incheon		Asia		It suggests that pulmonary function of asthmatic children was affected more when compared with healthy children, during the period of ADE
44	Hashizume et al. 2011	1990–2006 Nagazaki, Japan	Information on the day of death, sex, age at death, cause of death, chronic disease status, smoking habit for all deaths between 1990 and 2006 in the Atomic Bomb Survivors living in Nagasaki city were retrieved	Generalised linear Poisson regression model	Asia	Definition of Japan Meteorological Agency for an Asian dust event	All cause, circulatory and respiratory daily mortality were 0.5 % (95 % CI: −10.0, 12.2), 8.8 % (95 % CI: −10.0, 31.5) and −12.6 % (95 % CI: −33.7, 15.3) higher on days of Asian dust compared to other days
45	Hwang et al. 2004a	Spring 2002 Seoul, Korea	The total number of deaths per day. Data from the mortality records of the National Statistics Office	The daily average deaths between Asian dust and control days	Asia	The daily PM_{10} average during the Asian dust days was 295.5 μg m^{-3}	The rate of deaths during Asian dust weeks was increased 9.3 % for all causes 12.2 % for deaths of persons aged 65 years and older, 50.9 % for respiratory causes, but 10.4 % was decreased for cardiovascular causes
46	Kwon et al. 2000	1991–1998 Seoul, Korea	Daily mortality (cardiovascular and nonaccidental deaths). Data from the mortality records supplied by the National Statistical Office	Conditional logistic regression model	Asia	24-h mean TSP concentration during dust events was 115.2 μg m^{-3} (vs 84.6 μg m^{-3} during control days)	Results suggest that the ADE experienced in Seoul may have increased daily mortality, especially cardiovascular mortality
47	Kwon et al. 2002	1995–1998 Seoul, South Korea	Daily nonaccidental deaths. Mortality in persons younger than 65 and mortality in persons 65 and older were determined separately. The causes analysed were cardiovascular and respiratory disease and other causes. Data from the mortality records supplied by the National Statistical Office	Additive model approach with Poisson log-linear regression	Asia	The average PM_{10} concentration on the event days was 101.1 μg m^{-3}. It is 27.8 μg m^{-3} higher than that on control days	Estimated increase in the rate of deaths from 3-day moving averages of exposure was 1.7 % for all causes (0.6 % for each 10 PM_{10}μg. m^{-3}), 2.2 % for persons aged 65 years and older, and 4.1 % for cardiovascular and respiratory causes. Weak evidence that the ADE are associated with risk of death from all causes

Table 1 (continued)

ID	Reference	Date, location	Health outcomes, target population, data source	Method	Dust origin	Dust event definition	Main findings
48	Pan et al. 2006	40 days during the dust storm weather in 2004 Inner Mongolia of China	Respiratory health and PEFR. 120 exposed schoolchildren from 2 primary schools in Baotou City. Original data from questionnaires	The time-series analysis and multiple regression model	Asia	The concentrations of air PM_{10} and $PM_{2.5}$ increased obviously in the dust storm weather	The level of PM_{10} and $PM_{2.5}$ in the dust storm weather can increase the respiratory symptoms of the exposed schoolchildren and decrease the PEFR values of the lungs of the schoolchildren, and these effects can be reduced after a period of time. It suggests that the health effects of dust storm (PM) may be short-term and reversible effects
49	Ueda et al. 2010	2001–2007 Fukuoka, Japan	Data on emergency hospitalisations for asthma collected at Fukuoka National Hospital in Fukuoka. The subjects of this study were children under 12 years of age	Time-stratified case-crossover design and logistic regression	Asia	Data on AD events were obtained from the Japan Meteorological Agency. The occurrence of an AD event was generally determined by visibility-based observation	A 10 μg m^{-3} increase in suspended particulate matter and nitrogen dioxide (NO_2) at lag2–lag3 were significantly associated with an increase in asthma hospitalisation. However, they did not observe a significant association between asthma hospitalization and AD events
50	Yang et al. 2005a	1996–2001 Taipei, Taiwan	Daily admissions for stroke. Data from the National Health Insurance Program	Poisson regression model	Asia	Hourly PM_{10} concentration observed exceeded the air quality standard (125 μg m^{-3}) and lasted for at least 3 h	Statistically significant association between ADE and daily primary intracerebral haemorrhagic stroke admissions 3 days after the event. Non significant association between ADE and ischaemic stroke admissions 3 days following the dust storms

A number of adverse health effects, including respiratory diseases (among others asthma and pneumonia), cardiovascular diseases (ischaemic heart disease, cerebrovascular disease), cardiopulmonary diseases (COPD) and, more rarely, conjunctivitis and allergic rhinitis, are associated with dust. The Poisson regression is the method most used in the papers evaluated to analyse data. This is used routinely for analysis of epidemiological data from studies of large cohorts. The Poisson regression is typically implemented as a grouped method of data analysis in which all exposure and covariate information is categorised and person-time and events are tabulated (Loomis et al. 2005). In most studies of dust impacts on excess deaths/hospital admissions, a distinction is made between mortality/morbidity due to respiratory diseases, due to cardiovascular diseases and due to 'all-causes'. Except for one article, accidental deaths were always excluded from the analyses.

Classification of dust-health relationship

In order to investigate the relationship between dust and health, the 50 articles were grouped in four categories (Cat. 1, Cat. 2, Cat. 3 and Cat. 4) according to the presence/absence of statistically significant/not significant desert dust impacts on human health in the results (Table 1). A total of 21 studies showed a significant increase of mortality/morbidity in relation to a dust event or an air quality deterioration (Cat. 1, studies 1–21 in Table 1). A small fraction of these studies focussed on at-risk populations (children, elderly, and asthmatics). A further 9 papers show a trend towards a relationship (Cat. 2, 22–30 in Table 1). It is, however, important to note that 7 of these 9 studies were carried out in Tapei (Taiwan). In many of these studies, the authors suggest a possible inadequate sample size. By contrast, 11 studies conclude that dust is not associated with health effects (Cat. 3, N° 31 to 41 in Table 1). The remainder of the studies (9) produces less conclusive results (Cat. 4, N° 42 to 50 in Table 1). In these latter studies, researchers evaluated the impact of dust events on daily mortality/hospital admissions for different causes. In general, this last group of studies shows that there is a significant association between dust events and mortality due to respiratory and/or cardiovascular causes, but the association was not statistically significant for all causes.

Table 2 shows that both mortality and hospital admissions are studied in relation to human exposure to desert dust. Studies on dust impact on mortality are somewhat fewer than on hospital admissions. The majority of studies are concerned with the impacts of dust on morbidity or mortality for all causes and / or respiratory or cardiovascular causes. Studies dealing with the relationship between dust events and mortality for all-causes are spread over the three categories. On the other hand, relationships between desert dust and mortality as a consequence of cardiovascular or respiratory concerns are most often significant. When considering hospital admissions, the situation is different. While relationships between dust and hospital admissions from all-causes are significant in both studies, studies on the relationship between dust and hospital admissions for

Table 2 Frequencies of health effects cross referenced by the categorised findings of the studies

		Significant relationship between dust and health Cat. 1 (+ Cat. 4)	Positive but non-significant relationship between dust and health Cat. 2	No relationship between dust and health Cat. 3 (+ Cat. 4)
Mortality	All-causes	6	1	5
	Cardiovascular disease	8	1	1
	Respiratory disease	6	1	0
	Asthma	0	1	0
Hospital admissions	All-causes	2	0	0
	Cardiovascular disease	4	2	3
	Respiratory disease	6	1	8
	Asthma	6	2	2
	Paediatric asthma	4	0	0
	Rhinitis	0	1	0
	Conjunctivitis	0	1	0
	Cerebrovascular disease /stroke	4	0	1

cardiovascular or respiratory diseases are spread over the three categories. There are also a few more studies that conclude that there is no relationship between desert dust and hospital admissions for respiratory reasons, if we discount (paediatric) asthma. Studies with a positive but non-significant relationship between dust and health are diverse with respect to the types of health problems addressed.

Dust-health relationship - publication date

Of the 21 studies with significant results, 19 were published in the past 5 years (2007–2011). Furthermore, none of studies published before 2005 showed evident significant results. In contrast, 5 of the 11 studies concluding that there is no relationship between dust and health were carried out before 2007. It has been suggested that, for studies in Asia, one major reason why dust storms are either not associated with mortality or had no consistent association with hospital admissions is that, to date, studies looking at the impact of dust on health have not documented well the area in which, and the time in which, dust storms take place (Chan et al. 2008). It can be expected that a short-duration dust storm taking place during a wet period may have little significant impact on health in downwind reach areas. Conversely, however, there is evidence that people are becoming more concerned about the possible adverse effects of dust because dust events have increased in magnitude and frequency (Yoo et al. 2008). Many studies carried out in West Africa emphasise recent increases in desertification processes (e.g. Hountondji et al. 2006; Ozer et al. 2006). This strengthens the need to deepen our knowledge of dust impacts on health in this zone.

Dust-health relationship - dust origin

Figure 1 summarizes information on the links between dust origin and areas where studies of dust impacts on health have been conducted. Asian dust is by far the most frequently studied in this specific literature (65.3 %), and studies focus mostly on health effects in Asian countries (63.3 %). Other dust sources (Sahara and other deserts) are also explored but, despite the proximity to the Sahara, no study dealing with dust impact on health in West Africa has been published. In terms of significant impacts on health, studies on the effects of Saharan dust are the most numerous (11 vs 9 for Asian dust), whereas they are fewer in total (13 vs 32 for Asian dust). Overall, studies focussing on the effects of Asian dust are well distributed over the four categories, while studies on the impacts of Saharan dust have less contrasted results (among the 13 studies, 11 have a significant impact and 2 conclude the absence of a relationship between dust and health).

Three main trajectories of dust from the Saharan source area are distinguished (Middleton and Goudie 2001). The first is over thousands of kilometres and crosses the Atlantic Ocean to the United States, the Caribbean and South America (Chiapello et al. 1995; Kellogg et al. 2004); the second carries dust to the Mediterranean and Europe (Kellogg et al. 2004; Perez et al. 2008); and the third transports dust to the eastern Mediterranean and the Middle East (Kubilay et al. 2003; Middleton et al. 2008). Each of these trajectories can be seen at a specific period of the year, with intensity varying annually (Anuforom et al. 2007). With a few rare exceptions (e.g. D'Almeida 1986; McTainsh 1980), only recently have more authors begun to focus on the presence of desert dust, its physical characteristics and movement around the continent of Africa (Resch et al. 2007). Among other places, the dust is transported from the Sahara to the Gulf of Guinea by north-easterly trade winds in a south-westerly direction. It can thus be found specifically in Nigeria, Benin, Togo, Ghana and the Côte d'Ivoire (Sunnu et al. 2008). According to D'Almeida (1986), overall 60 % of the total particles from the Sahara Desert are transported to the Gulf of Guinea. The number of particles, mass distribution, dust flows, deposition rate and the mean size of the particles have been estimated in several countries, especially in Ghana (Afeti and Resch 2000, Resch et al. 2007; Sunnu et al. 2008), Mali (McTainsh et al. 1997) and Nigeria (Anuforom 2007). These studies show that the dust quantity (which varies

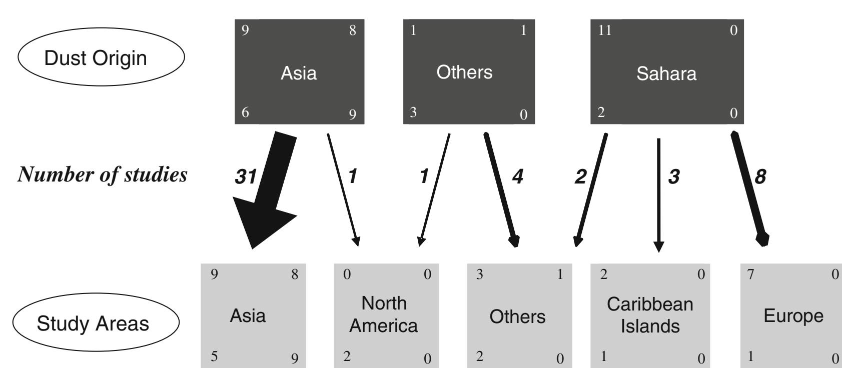


Fig. 1 Relationship between dust origin areas and study areas with health effects based on the systematic literature review (*N*=50). *Numbers in the boxes* Top right corner: Cat. 1 studies; top left corner: Cat. 2 studies, lower right corner: Cat. 3 studies; lower left corner: Cat. 4 studies

from year to year) is greater in the northern parts of these countries and that the dust particles become finer in size as they move further south.

The main constituents of Saharan dust particles are clays, minerals (especially iron, but also copper and zinc), and quartz (Linares et al 2010). Saharan dusts sampled from the Harmattan plume and over Europe are dominated by silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3)—a characteristic they share with North American and Chinese dusts. The concentrations of these two major elements are similar to those found in earth rocks (Goudie and Middleton 2001). Inhaling silicon dioxide in very small quantities can cause silicosis, bronchitis, or cancer, as the dust becomes lodged in the lungs and continuously irritates them, reducing lung capacity. Details of the effects on human health of exposure to aluminium oxide can be found in Krewski et al. (2007). Saharan dust also carries large amounts of pollens and microorganisms such as bacteria and fungi, as well as related protein and lipid components. We refer to the specialised literature for more information about the potential health risks associated with these biogenic factors (Griffin 2007; Kellogg and Griffin 2006). Particulate matter can also contain endotoxins, which are components of the bacterial wall that can cause respiratory and systemic inflammatory responses, and exacerbate lung disease (Sandstrom and Forsberg 2008).

Dust event definition—health effects

Table 3 summarises the dust event criteria crossed by categories of study results. In all these studies, a dust event is considered based on a daily time step. Sometimes, high hourly PM_{10} concentrations are considered for several hours, although most of the time, they are based on the mean PM_{10} concentrations over 24 h. A dust day is defined either when a predefined threshold is reached or by observation (comparison of mean daily PM_{10} concentration during dust days and during control days). Levels are expressed in absolute or relative units. The reduction of visibility is used in one case (Gyan et al. 2005) but PM_{10} concentration is the reference indicator in nearly all other papers. The methods of measurement of PM_{10} concentrations, based on samples from a variable number of in situ stations, are varied. For instance, beta-ray absorption (Chen et al. 2004; Chen and Yang 2005; Cheng et al. 2008), laser spectrometry (Perez et al. 2008) and pump samplers (Wiggs et al. 2003) have all been used. It is interesting to note that the levels are not automatically higher in Cat. 1 articles. Similar definitions are sometimes used in studies classified in different categories. In all cases, dust events lead to particulate levels that exceed international level guidelines (Brunekreef and Forsberg 2005; Ozer et al. 2006). Today, according to the WHO, the acceptable annual mean value of PM_{10} is 20 μg m^{-3} and mean values over 24 h exceeding 50 μg m^{-3} are considered to exceed acceptable standards.

Besides the criteria presented in Table 3, some researchers used other types of information to define dust events. Among the 50 studies listed in Table 1, satellite images (MODIS, NOAA/AVHRR) were used in two cases, but in combination with other data (Chan et al. 2008; Goto et al. 2010). In one study, Saharan dust days (SDDs) were defined by combining light detection and ranging (LIDAR) observations and analyses from operational models (Mallone et al. 2011). Finally, some studies used direct information from the Ministry of Special Agency about dust events (Ueda et al. 2010; Watanabe et al. 2011; Yoo et al. 2008).

In order to investigate the impact of dust on human health in a quantitative manner, the 21 studies that indicated dust having a significant impact on human health were evaluated further. Definitions or conditions (based mostly on terms of PM_{10}) associated with dust events in these studies are listed in Table 1. PM concentrations in the size range 84 μg m^{-3} (Lee et al. 2007) to 600 μg m^{-3} seem to be associated with the greatest impact on human health in terms of mean daily concentration (Hwang et al. 2008). In central China, dust events with a lag of 3 days have been shown to be a risk factor for daily hospitalisation for respiratory and cardiovascular diseases (Meng and Lu 2007). Studies reported that, in Korea, dust events are associated with increased daily mortality (Lee et al. 2007), stroke, asthma (Lee et al. 2008; Yoo et al. 2008) and atopic asthma (Hwang et al. 2008). Dust storms also have an impact on cardiopulmonary emergency admissions (Chan et al. 2008) and on the respiratory symptoms of subjects with bronchial asthma (Park et al. 2005) in Taiwan. In addition, a statistically significant association has been recorded between Asian dust events and daily pneumonia admissions 1 day after the event (Cheng et al. 2008). Wind-blown Saharan desert dust falling on Europe from March 2003 to December 2004 has been temporally associated with an increased daily mortality of 8.4 % per 10 μg m^{-3} increase in $PM_{10–2.5}$ in Barcelona, Spain, although the increase in the average of mass concentration of PM was modest: 16.4 (46.3) against 14.9 (38.9) μg $PM_{10–2.5}$ (PM_{10}) m^{-3} during Saharan dust days and non-Saharan dust days, respectively (Perez et al. 2008). These findings support results obtained for a 10-year time-series analysis of morbidity in Cyprus. All-cause and cardiovascular admissions were 4.8 % and 10.4 % higher on Saharan dust storm days, respectively (Middleton et al. 2008). On the Caribbean island of Trinidad, a deterioration in visibility due to increased Saharan dust cover from not dusty (visibility =16 km) to very dusty (visibility=7 km) is temporally associated with an increased daily hospital admission rate from 7.8 patients to 9.25 when climate variables such as barometric pressure and humidity were kept constant (Gyan et al. 2005). More recently, it has been shown that the number paediatric hospital admissions increases for up to 7 days from the peak of dust cover (Monteil 2008).

Table 3 Panel of definitions of dust events by the categorized findings of the studies[a]

		Significant relation between dust and health Cat. 1	Positive but non-significant relation between dust and health Cat. 2	No relation between dust and health Cat. 3	Mixed results depending on type of diseases or pollutants Cat. 4
Dust event definitions	Hourly PM_{10} concentration	>125 μg m^{-3} (min 3 h)[b] [2] >150 μg m^{-3} (urban) or >100 μg m^{-3} (rural) [15]	>125 μg m^{-3} (min 3 h) [22,28,29,30]		>125 μg m^{-3} (min 3 h) [50]
	Daily PM_{10} concentration	>85 μg m^{-3} [16]		>50 μg m^{-3} [31]	>115 μg m^{-3} (urban) and
		>100 μg m^{-3} [1,8] >300 μg m^{-3} [14]		>130 μg m^{-3} [34]	>100 μg m^{-3} (rural) [42]
		Rural at least 50 % urban[c] [18]			
		>99th percentile [7]			
	Daily visibility	=<15 km [4]			
Dust event observations	Hourly PM_{10} concentration			120 μg m^{-3} [32]	
	Daily PM_{10} concentration	>600 μg m^{-3} [5]	110 (62) μg m^{-3} [22,29]	>600 μg m^{-3} [35,36]	295.5 μg m^{-3} [45]
		47.5 (31) μg m^{-3} [d] [6]	112 (55) μg m^{-3} [23,25,28,30]	>100 μg m^{-3} [38]	101 (73) μg m^{-3} [47]
		84 (56) μg m^{-3} [10]	126 (58) μg m^{-3} [24]	67 (52) μg m^{-3} [39]	112 (55) μg m^{-3} [50]
		112 (55) μg m^{-3} [2] 188 (60) μg m^{-3} [17]		263 (42) μg m^{-3} [40]	115 (85) μg m^{-3} [46]
		188.5 (66) μg m^{-3} [9]			

[a] Values in square brackets refer to the identifier (ID) of the study noted in Table 1. In some studies, information on dust event definition is not available

[b] The authors of this study defined a dust event as when the hourly PM_{10} concentration is greater than 125 μg m^{-3} for a minimum period of 3 consecutive hours

[c] In this study, a dust event is defined when the value of daily PM_{10} concentration recorded in a rural environment is at least half of the value recorded in urban areas

[d] The authors of this study observed a mean daily PM_{10} concentration of 47.5 μg m^{-3} during dust event (while a mean daily PM_{10} concentration of 31 μg m^{-3} during control days)

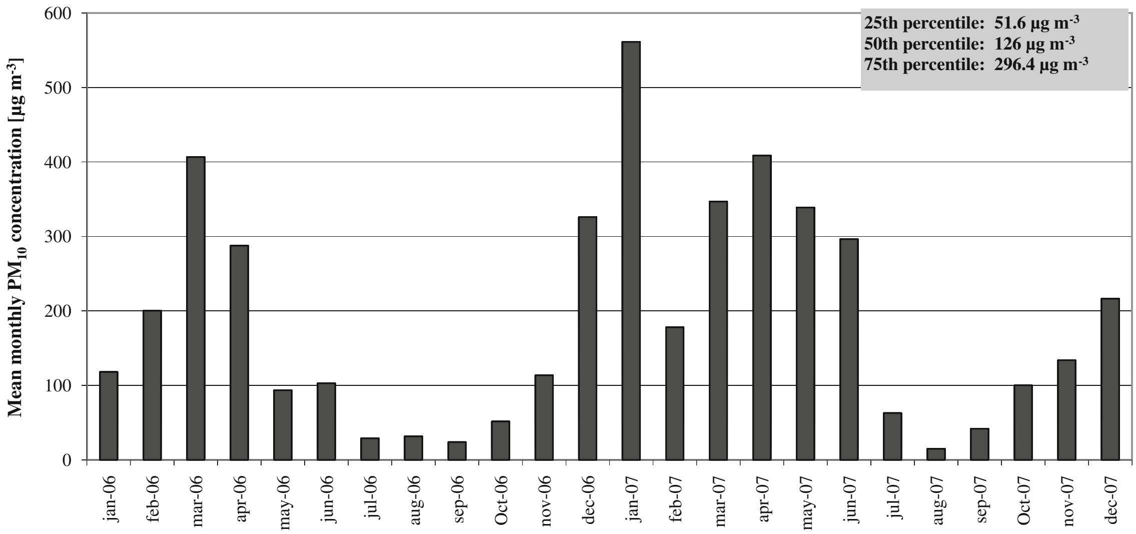


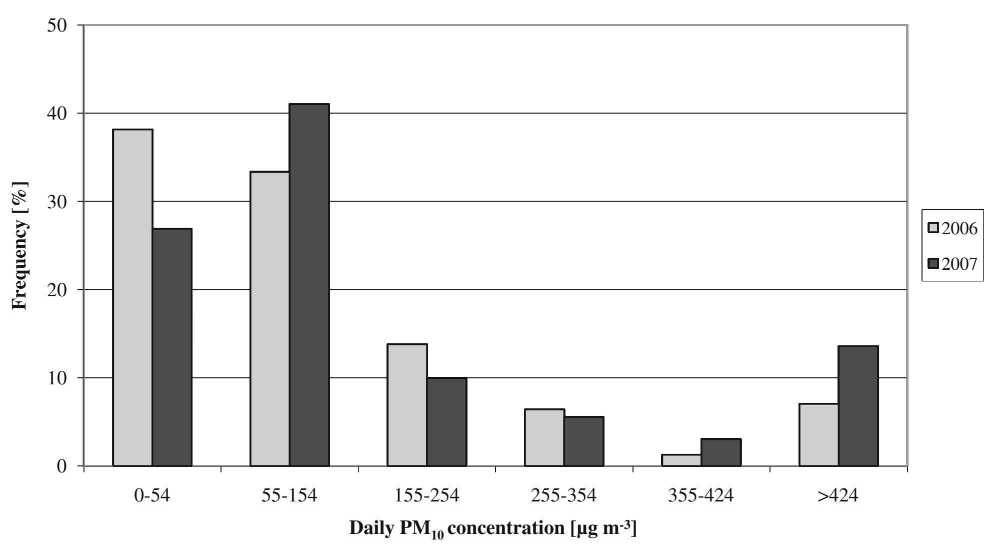
Fig. 2 Monthly PM_{10} concentration [µg m^{-3}] at Banizoumbou (Niger) in 2006 and 2007 (Source: Sahelian Dust Transect; AMMA; http://amma.mediasfrance.org/)

What is happening in West Africa?

Historically, in West Africa, there has been an absence of detailed ground-based meteorological data, hence no standard definition of increased dust impacting on human health has been established in the literature (Molesworth et al. 2002). However, recently (2006–2007) PM_{10} data were recorded in a rural Sahelian station, located in Banizoumbou (Niger). Figures 2 and 3 show the mean monthly PM_{10} concentrations expressed in micrograms per cubic metre and the distribution of the number of days with selected daily PM_{10} concentrations [µg m^{-3}], respectively.

From these figures, it is evident that levels of PM_{10} concentrations recorded at Banizoumbou (Niger) in 2006–2007 are higher by far than those found in the 21 studies evaluated here that show a significant positive dust–health relationship. Based on comparison with these values (Table 1, column *Dust event definition*), at Banizoumbou, we would record one dust event every 4 days according to some sources (Park et al. 2005; Lee et al. 2007) and more than one every 2 days according to others (Lee et al. 2008; Middleton et al. 2008; Monteil 2008). A daily PM_{10} concentration exceeding 600 µg m^{-3} recorded during a dust episode in Seoul in 2002 (Hwang et al. 2008) was counted 14 times in 2006 and 27 times in 2007 at Banizoumbou. Maximum values of daily PM_{10} concentration were 2,714 µg m^{-3} and 4,024 µg m^{-3} noted on 8 March 2006 and 4 February 2007, respectively, in this same station. Based on visibility data—a proxy for air quality—some authors recorded similar values in other parts of the Sahel. For instance, an extreme mean daily PM_{10} concentration of 1,942 µg m^{-3} and an mean monthly PM_{10} concentration of

Fig. 3 Distribution of the number of days with selected daily PM_{10} concentration [µg m^{-3}] at Banizoumbou (Niger) for 2006 and 2007 (Source: Sahelian Dust Transect; AMMA; http://amma.mediasfrance.org/))



344 μg m^{-3} were recorded at Nouakchott (Mauritania) in 2000 (Ozer et al. 2006). In 1984, the average annual PM_{10} concentration reached a value of 245 μg m^{-3} in Gouré (Niger) (Ozer et al. 2005). In 41 villages across Niger, a survey was undertaken to assess farmers' views about the relative importance of perceived constraints to agricultural production. Wind erosion related health problems were of more concern than crop damage or loss of topsoil by wind erosion. Eighty percent of villagers (N=892) reported health symptoms to be more severe during the Harmattan season, when people are exposed for several consecutive days to high level of dust (Bielders et al. 2001).

What are the effects of much larger PM mass concentration near the sources, especially near the Sahara? Currently it is hard to say since no systematic particulate air pollution data are available for the Sahel of West Africa (Baldasano et al. 2003) and because the potentially affected countries do not have good-quality public health data that can be used to adequately support such studies (Mathers et al. 2005). With the exception of a few studies focussing on the effects perceived by local populations, little is known. Are the effects of Saharan dust different near the source than in Europe or in Carribean Islands? How sensitive are people living in the Sahel to large amounts of coarse mineral dust? Are there any differences by age groups? What are the health effects after exposure to high levels of dust concentrations for several consecutive days? What are the most recurrent diseases in dust concentration regions? These are some of the many questions that may arise and require answers.

Conclusion

The objective of this study based on a systematic literature review was to learn more about the relationship between desert dust and health in the world and to highlight West Africa as a study area of interest.

Specific studies on the impact on human health of desert dust carried out in other parts of the world are reasonably consistent. As a group, these studies show that air quality deterioration caused by desert dust is associated with significant impacts on human health. Although some results appear to show a less pronounced impact, no major contradiction was revealed. While few studies on Saharan dust have been published, those that are available indicate that Saharan dust has a significant impact on human health, but new studies are called for here. Many studies carried out close to dust sources less globally important than the Sahara (e.g. Asia) or spatially removed from the Sahara (e.g. Europe, America), but nevertheless revealing an association between desert dust and increasing morbidity/mortality, have reached alarming conclusions.

In the premier research platform for information in science, there has been no published work to date evaluating the impact of dust on health in West Africa. We plan to carry out further research in other literature databases and in the printed literature to search for relevant papers that may not be indexed in the major literature databases. Nevertheless, there is no doubt that studies on health effects in West Africa remain in a minority compared to those focussing on other regions. It is clear that further studies of Saharan dust are vital, especially in West Africa, to further investigate the impact of this dust on human health.

We feel that this is a major research need; dust events in West Africa are more frequent and more intense than anywhere else but the health effects remain almost completely unevaluated in this region. It is hoped that these findings will stimulate further work in this field to increase our knowledge of the impacts of dust on human health, and to quantify the risk in vulnerable populations of West Africa. All such studies must be encouraged; our review has raised many questions and it is a matter of public health to begin to find answers.

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