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Review

What do we know about effects of desert dust on air quality and human health in West Africa compared to other regions?

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ABSTRACT

This study aims to compare, on the one hand, the geographical distribution of the desert dust source areas, their contribution to quantities emitted into the atmosphere, the trajectories and the quantities deposited, with on the other hand the areas of research interest focused on the desert dust impacts on air quality and/or human health. Based on a systematic review of the literature using the ISI Web of Knowledge database, we found 231 articles published over the last decade on the desert dust impacts on air quality. Of these, 48% concerned Asian dust and 39% Saharan dust, with the remaining 13% divided between the other dust source areas. However, only one of these studies addressed the worsening air pollution in West Africa, even though it is very close to the Sahara, the greatest contributor to the global dust budget. Moreover, there have been very few studies (41) looking at the direct links between desert dust and human health; in this context too, no interest has been shown in West Africa. Yet this region is also among the areas in which morbidity rates have been noted to be far higher than those found in other regions of the world, and where respiratory infections alone account for more than 20% of the causes of infant mortality. This survey highlights a clear imbalance between those areas most exposed to dust and the most studied areas in terms of dust impacts. Given these findings and the often alarming results published about other regions of the world, we advocate a revival of interest in research on West Africa in order to achieve a better understanding of the desert dust impacts on air quality and health among the populations of this region.

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1. Introduction

In recent years, links have been established between the natural environment and human health. Today, no doubt remains on the existence of effects – mostly negative – of the former on the latter (Kalkstein and Smoyer, 1993; McMichael, 2001). According to Craig et al. (1999), the resurgence and redistribution of disease mirror changes in ecological and climatic conditions. It is estimated that 25 to 33% of the global disease burden can be attributed to environmental factors (Smith et al., 1999). A great deal of research is being done on this subject and interest in it has been growing slowly but surely.

Through an in-depth review of the available literature, this study aims to highlight the specific links between the areas that are most

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exposed to desert dust and the areas of interest in the studies about the desert dust impacts on air quality and human health, with a view to ascertaining the situation of West Africa in this context.

2. Origin and movement of desert dust

The desert dust source areas and quantification of the emissions are not a new issue. Previously, several methods were used to identify these areas: surface dust observations at meteorological stations, analysis of trajectories using isobar data, and the use of mineral tracers (Middleton and Goudie, 2001). These techniques are still used and are undoubtedly useful although limited, notably because of the difficulty of covering the world's remoter regions and because of the scarcity of meteorological stations. Other and more recent methods, such as ground-level observations of the horizontal visibility — which can be seen as a proxy indicator of dust (N'Tchayi Mbourou et al., 1997), are often highlighted in the literature (e.g. Anuforom, 2007; Engelstaedter et al., 2006; Mahowald et al., 2007; Ozer, 2001; Ozer et al., 2006b). But horizontal visibility also poses some problems, due to the scarcity of meteorological stations in some regions and the availability of data collected (Anuforom et al., 2007; Ozer et al., 2005). Furthermore, Mahowald et al. (2007) note that visibility is not necessarily directly linked to the aerosol concentration, because visibility may be influenced by humidity, cloud cover and precipitation. They also say that highly local effects, such as a busy road nearby, can influence aerosol quantity close to a station. With the relatively recent developments in remote sensing, and above all the emergence and use of several tools such as the Total Ozone Mapping Spectrometer absorbing Aerosol Index (TOMS AI) (Herman et al., 1997) and the Infrared Difference Dust Index (IDDI) (Legrand et al., 1989), research on dust emissions and its spatial distribution in the atmosphere has improved enormously in recent years (Engelstaedter et al., 2006).

Nine regions contribute to the total global production of desert dust (Fig. 1): North Africa (Sahara), South Africa, the Arabian Peninsula, Central Asia, Western China, Eastern China, North America, South America and Australia (Prospero et al., 2002; Tanaka and Chiba, 2006). Overall, the different models used estimate that global dust emission varies by a factor of slightly more than two, although extreme values from 1018 Tg year^{-1} (Miller et al., 2004) to 3000 Tg year^{-1} (Tegen and Fung, 1994) have been established over the last 15 years (Engelstaedter et al., 2006). Estimates of the contribution of the different source areas vary by study and are more difficult to make, especially as each source area follows a distinct seasonal cycle (Engelstaedter and Washington, 2007). However, the studies addressing these problems all agree that North Africa is the main source area (over 50%) (e.g. Engelstaedter et al., 2006; Ginoux et al., 2004; Washington et al., 2003). On the other hand, controversial findings suggest that this area as a whole may be a dust source or that within this region there are predominant and more persistent areas (mainly the Bodélé Depression in the Lake Chad Basin, as well as Mali and Mauritania in the western Sahara), which are essentially uninhabited arid regions located around the 200–250 mm isohyet (D'almeida, 1986; Middleton and Goudie, 2001; Prospero et al., 2002). Recently, Tanaka and Chiba (2006) calculated that the Sahara could account for 58% (or almost 1100 Tg year^{-1}) of the total global dust emission.

Fig. 1 shows the location of the nine dust source areas and the estimated dust emission values, expressed in Tg year^{-1} (Tanaka and Chiba, 2006).

Thanks to global dust transport models, the authors were able to map the trajectories, atmospheric load and the scale of the dust deposits (Tanaka and Chiba, 2006; Zender et al., 2003). The association of these models with satellite data appears to be helpful in determining the regions affected by dust events (Prospero, 1999a). For several years now, it has been widely accepted that large quantities of mineral dust are transported over the oceans from arid continental regions to all the world's regions (Prospero et al., 2002; Washington et al., 2003). Based on estimates made by Tanaka and Chiba (2006), Fig. 2 shows the geographical distribution of the desert dust atmospheric loads, in mg m^{-2}.

The authors distinguish three main trajectories from the North Africa source area (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; Ginoux et al., 2004; Kellogg et al., 2004; Perry et al., 1997); the second carries dust

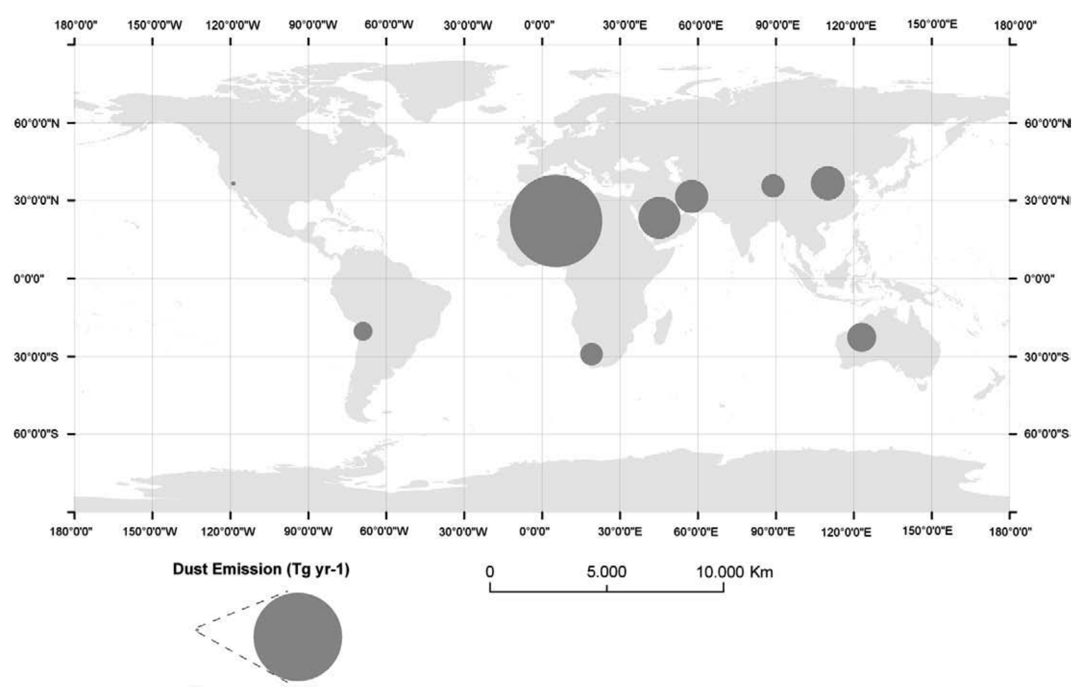

Fig. 1. Location of the source areas and scale of the dust emissions.
Adapted from Tanaka and Chiba, 2006.

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to the Mediterranean and Europe (Kellogg et al., 2004; Perez et al., 2008; Querol et al., 2001); 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, 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). The dry, dusty wind is one of the predominant atmospheric phenomena in West Africa, known as the Harmattan. It blows from late November to March in the sub-region (Afeti and Resch, 2000). 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, the deposition rate and the mean size of the particles have been estimated in several countries, especially in Ghana (Afeti and Resch, 2000; Breuning-Madsen and Awadzi, 2005; 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 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.

3. Impacts of desert dust on air quality

Air pollution has many causes. Purely anthropogenic factors – such as industry, road traffic and fuelwood in developing countries – all release polluting particles into the air and contribute to deteriorating air quality. Moreover dust particles, whether of natural origin and/or partially human from bush fires or practices that lead to desertification, affect air quality (O'Hara et al., 2000; Sunnu et al., 2008; Zender et al., 2004). Based on measures of horizontal visibility reduced by mineral dust, the results of a study in Mauritania show that air quality is seriously degraded following wind erosion processes (Ozer et al., 2006b). The specific studies on air quality are mainly based on various indicators such as the mineral concentrations of SO_2, NO_2, O_3, and CO, in total suspended particulates (TSP), in particulate matter (PM) (e.g. Baldasano et al., 2003). There are several categories of PM, based on size criteria. In most cases, the literature refers to PM_{10} and $PM_{2.5}$. With this term, the number represents the upper size limit of the particles included in the categories, expressed in µm (micrometres). These particles vary in their composition, depending on their origin (Querol et al., 2001). Saharan dust is mainly made up of clay minerals, quartz, calcium and magnesium carbonates, while particles of anthropogenic origin seem to be mainly composed of carbon-containing particles, sulphates and nitrates (Afeti and Resch, 2000; Rodriguez et al., 2001).

Fig. 3 summarises the air quality standards, defined at the national level except for the European Union. In the United States, the Environmental Protection Agency has defined the standards (National Ambient Air Quality Standards — US EPA NAAQS) for suspended particles (US EPA, 2006). Until 1986, they were based on the total suspended particulates (TSP). From 1987, the attention focused on PM_{10}. Since 1997, the $PM_{2.5}$ concentration has been an additional criterion to the PM_{10} concentration. In the United States today, the following standards apply: the acceptable annual mean values of $PM_{2.5}$ and PM_{10} are respectively 15 $\mu g\ m^{-3}$ and 50 $\mu g\ m^{-3}$ and the mean values over 24 h exceeding respectively 65 $\mu g\ m^{-3}$ and 150 $\mu g\ m^{-3}$ are considered to exceed the standards (Prospero, 1999a). In Europe, the Directive 1999/30/EC (EU, 1999) on air quality laid down the standards (EU Air Quality Limit Values — EU AQLV), based exclusively on PM_{10} concentrations. The annual PM_{10} concentration must not exceed 40 $\mu g\ m^{-3}$ and the daily concentration may reach a maximum of 50 $\mu g\ m^{-3}$, not to be exceeded more than 35 days per calendar year. From 2010, the standards will be tightened: previously 40 $\mu g\ m^{-3}$, the annual average PM_{10} concentration will be 20 $\mu g\ m^{-3}$ and a daily concentration of up to 50 $\mu g\ m^{-3}$ must not be exceeded more than seven days per calendar year (EU, 1999). The other data have been taken from diverse sources (Australian Government, Department of the Environment, Water, Heritage and the Arts, 2005; Aziz, 2006; Baldasano et al., 2003; Bae et al., 2004; CETESB, 2002; Cicero-Fernandez et al., 2001; Gozun, 2006; Ministry of Environment. Government of British Columbia, 2006; Ministry of

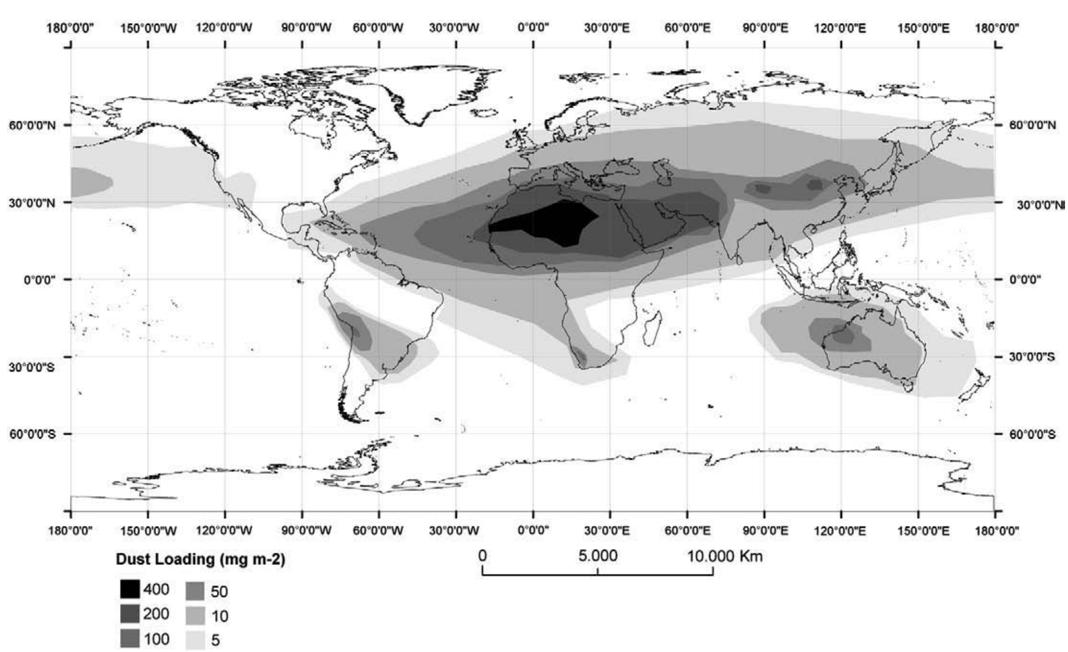

Fig. 2. Geographical distribution of the dust atmospheric loads.
Adapted from Tanaka and Chiba, 2006.

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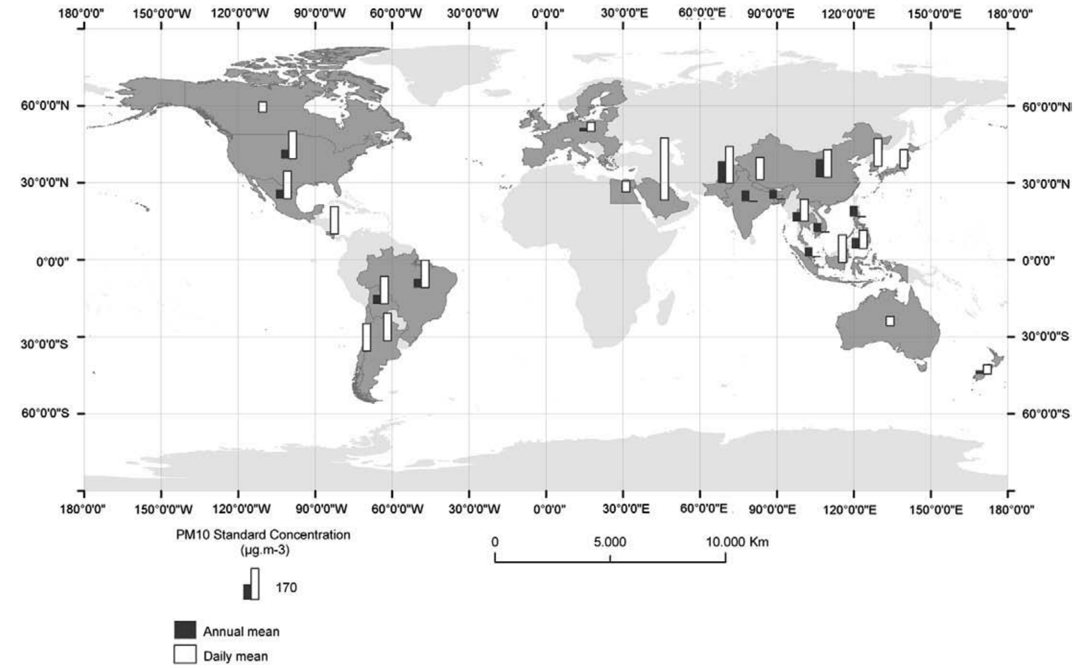

Fig. 3. National (or regional) standards for air quality (PM_{10}).

Social Development (New Zealand), 2008; Olcese and Toselli, 1998; Qian et al., 2001). In Fig. 3, if a country only shows the annual average tolerated PM_{10} concentration or only the maximum PM_{10} concentration in a day, that means we were unable to obtain the other value or that no standard has been defined.

In Spain, Querol et al. (2001) note that the $PM_{2.5}$ and PM_1 levels are consistent with the daily cycle of gaseous pollutants emitted by traffic. The same applies to the $PM_{2.5}/PM_{10}$ ratio. However, the TSP and PM_{10} do not follow the same trend and the PM_{10} peaks appear to be mainly recorded during Saharan air intrusions. By comparing the contribution of Saharan dust with the presence of particles measuring respectively 10, 5 and 2 µm in Ghana, Sunnu et al. (2008) come to the same conclusion. That is why we will focus exclusively on PM_{10} particles in the rest of this article. The coarse particles (PM_{10}) seem capable of being deposited in the bronchial passages and so appear to have an impact on respiratory conditions, leading to asthma, chronic obstructive pulmonary disease, pneumonia and other respiratory tract infections. The finer particles ($PM_{2.5}$) appear to be more linked to cardiovascular problems, since they can reach the pulmonary alveoli (Sandstrom and Forsberg, 2008).

An initial in-depth literature search on the areas of interest in the studies linking desert dust and air quality was carried out using the ISI Web of Knowledge database. The following key words were used: 'PM_{10}' AND 'dust storm', 'sand storm', 'African dust', 'Saharan dust', 'Asian dust', 'Yellow dust' or 'dust events', together with an additional criterion on the publication date of studies (between January 1999 and December 2009). After checking the relevance of each result obtained, the studies were classified by the dust source area and by the location of the study area affected by any air degradation. Fig. 4 summarises the information by showing the weight given to the different areas of interest in the studies on the dust impacts on air quality with an indication of the desert dust origin. Of the 231 publications selected, 48% deals with Asian dust and 39% with African dust, while the remaining 13% is divided between the other dust emission source areas. As regards the distribution of the interest in areas affected by an increase in the PM_{10} concentration, 109 of the 231 studies (i.e. 47.2%) are on Asia, 81 and 19 studies (i.e. 35.1% and 8.2%) focus respectively on Europe and the United States, while four or six papers concern Latin America, the Middle East and Oceania (i.e. 7.4% for all these areas). Lastly, only three studies (i.e. 1.3%) focused on air pollution in Africa (Egypt, Tunisia and Mauritania) and the decimal parts (0.8%) comprise two studies carried out globally.

4. Impacts of desert dust on human health

Airborne dust particles also affect human health, through their impact on local and regional air qualities (Anuforom et al., 2007; Sassen et al., 2003). From all the studies cited so far, several mention the potential effects of dust particles on human health (e.g. Anuforom et al., 2007; Engelstaedter et al., 2006; Kellogg et al., 2004; Mahowald et al., 2007; Sassen et al., 2003), but very few of them present quantitative results.

A second literature review was carried out, again using the ISI Web of Knowledge database. The objective was to identify all work presenting specific results on the potential desert dust impacts on human health. The following key words were entered: 'Health', 'Mortality', 'Morbidity', 'Respiratory', 'Asthma' or 'Cardiovascular' AND 'dust storm', 'sand storm', 'African dust', 'Saharan dust', 'Asian dust', 'Yellow dust' or 'dust events', while keeping the additional criterion on the publication date of studies (1999–2009). As for the link between the dust source and air quality, the relevance of each publication resulting from the set target request was checked. The studies were then grouped together according to the dust source area and the location of the area in which various health issues are being studied. In all, this analysis led to the selection of only 41 publications. Of these, 29 deal with Asian dust and 9 with African dust, while the other addressed dust from arid areas of Australia, North America and the Aral Sea region. Concerning the distribution of the areas of interest in which the population health effects are studied, 28 of the 41 studies are about Asia, 5 are on the Caribbean, and 4 studies were done on Europe and 2 on North America; Australia and the region to the south of the Aral Sea were the focus of the latter two publications. Fig. 5 summarises the links between the desert dust source areas and the importance of different areas of interest in studies on the dust impacts on human health.

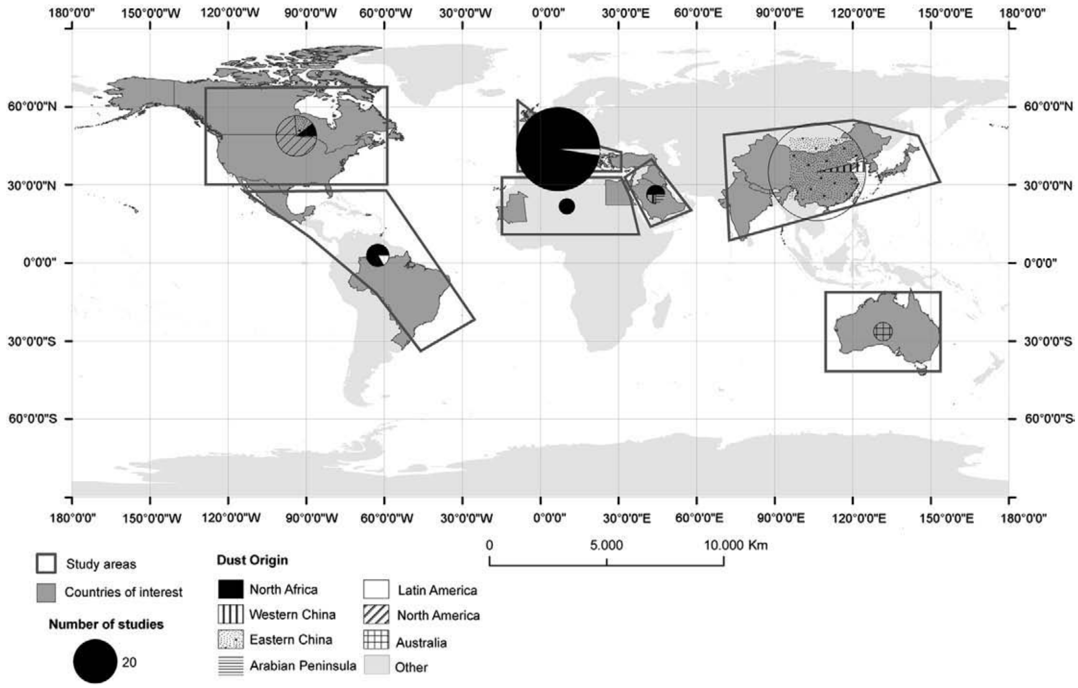

Fig. 4. Importance of the number and distribution of the studies on air quality according to the dust source area.

5. Discussion

Figs. 1 and 2 include two noteworthy points: (i) North Africa is the main dust emission source area, alone responsible for generating over 50% of the total desert dust found in the atmosphere and almost five times as much as the second biggest source (the Arabian Peninsula) (Fig. 1); and (ii) although a global transport process affects the vast majority of the Earth's surface, it appears that the atmospheric loads – and thus the deposits – are higher when close to the sources. West Africa is by far the most exposed region to atmospheric dust event (Fig. 2).

A comparison with Fig. 4 underlines three major findings. The first is that Asia is the world's most studied region in the literature linking desert dust and air quality. Half of the relevant publications resulting from the first request are about the role of Asian dust in the degradation of air quality in countries on the same continent, mainly China, Taiwan and South Korea. It appears that the whole of this region is only affected by Asian dust (Fig. 4), mainly from the Gobi Desert (Prospero et al., 2002), although this is only the third source area in terms of quantities emitted, after North Africa and the Arabian Peninsula (Fig. 1). Moreover, some research has been done on the contribution of this dust to the degradation of air quality in North America, even though according to

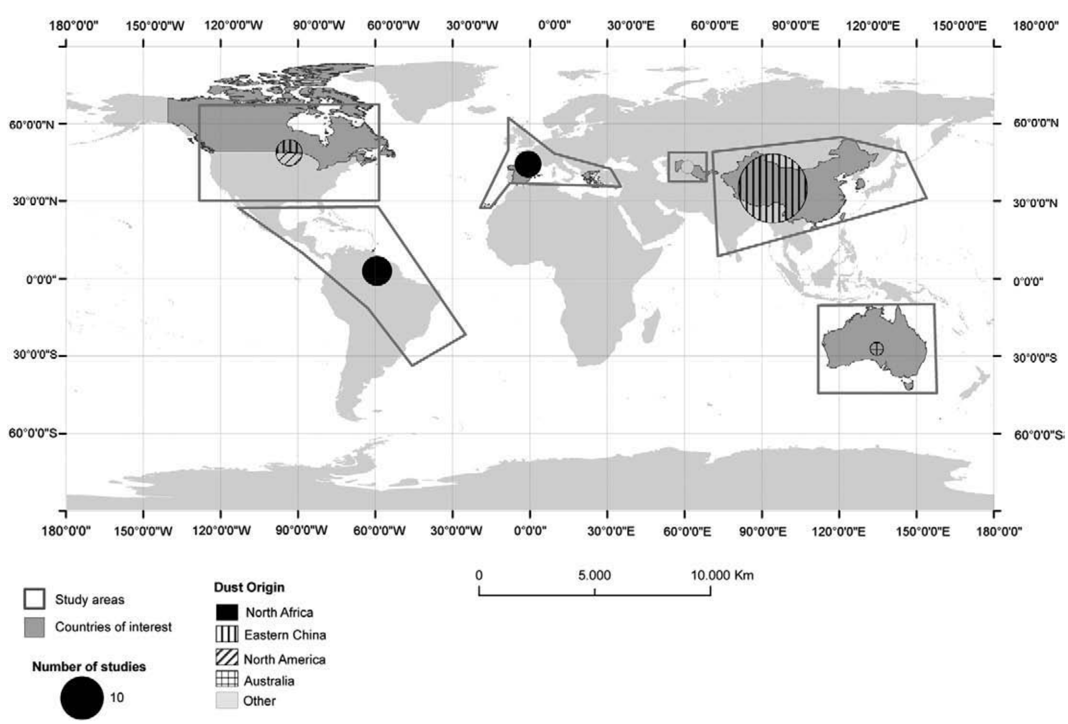

Fig. 5. Geographical distribution of the studies on human health according to the dust source area.

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Fig. 2 the dust drift from Asia to this continent seems to be limited. The second finding is that, in terms of dust origin, the second most common source area in the literature is North Africa. But unexpectedly, the 91 listed studies addressed the effects on air quality mainly in Europe (78 including 48 in Spain alone), the Middle East (4), Latin America and North America (6), and very few in Africa (3 including 1 in Mauritania, 1 in Egypt and 1 in Tunisia). The third finding is that in spite of the relatively low quantity of emissions and a more local range for the dust movements in some source areas, several studies focused on air quality in regions close to secondary source areas, such as several cases seen on North America, Australia and Latin America. These three findings underline an apparent imbalance between the relative importance of the different source areas and the interest of the scientific community in air quality in areas close to these sources, which are inevitably more exposed to the dust. Table 1 shows a comparison of air quality measures in West Africa with those made in the world's other regions. With the few studies undertaken in several West African countries, it can be seen that whichever indicator is used, the PM_{10} concentration values recorded or estimated are systematically higher when close to source areas. No standard has been defined in Africa (Fig. 3), but the values cited in the studies done in Mali (Gillies et al., 1996; McTainsh et al., 1997) and more recently in Niger (Ozer, 2005; Ozer et al., 2005) and Mauritania (Ozer et al., 2006b) reach levels that far exceed the standards fixed in any other region of the world (Fig. 3).

A comparison with Fig. 5 raises questions and highlights more glaring gaps in the scientific research. First, it is clear that only a very limited number of publications have quantified the direct association between desert dust and human health. Yet there have been many studies on the effects of air pollution generally on health. Research can be divided into studies focused on indoor air pollution and those addressing outdoor air pollution. The first category is of less interest to us, as it is not closely linked to the scope of this paper, although it should be noted that there is plenty of literature on this issue (Bruce et al., 2000; Ezzati, 2005). The studies generally concentrate on developing countries, with Africa often as the main focus, in particular due to the living conditions of the majority of the people there (Ezzati and Kammen, 2001). Regarding the effects of outdoor pollution, one can for example refer to Romieu et al. (2002), who counted some 20 studies exclusively addressing urban pollution sources (industrialisation, road traffic) in South America and, to a lesser extent, in Asia. Several studies have also been done on outdoor air pollution's effects on health in sub-Saharan Africa (Bousquet et al., 2003; Fourn and Fayomi, 2006), although only one of them mentions the potential role of natural mineral dust (Glew et al., 2004) among the contamination factors. The second striking point is the complete absence of studies done in West Africa. Yet, in Asia, previous studies reported a close association between mineral dust outbreaks and deaths from cardiovascular and respiratory causes in Seoul, Korea, suggesting that persons with advanced cardiovascular and respiratory diseases may be sensitive to dust storms (Kwon et al., 2002). Similar results were obtained in Taipei, Taiwan, where increases in respiratory diseases and of the total mortality were of 1.12% and 0.72% per 10 $\mu g\ m^{-3}$ increase in PM_{10}, respectively, during Mongolian dust outbreaks (Chen et al., 2004). In Central China, dust events have been seen as a risk factor for daily hospitalisation for respiratory and cardiovascular diseases (Meng and Lu, 2007). Other studies in Taiwan and in Korea indicated a statistically significant association between Asian dust events and daily pneumonia admissions one day after the event (Cheng et al., 2008). In addition, dust storms are impacting on the respiratory symptoms of patients with bronchial asthma (Park et al., 2005; Yoo et al., 2008). Moreover, studies done in other regions of the world have underlined two key points. Firstly, desert dust has significant effects in regions close to secondary source areas, as shown by Rutherford et al. (1999) in Brisbane, Australia. Although a general association could not be established, the study's findings indicate that some dust events are significantly linked with changes observed in the severity of asthma. Secondly, significant effects have been noted in regions far from the main sources. Here, Perez et al. (2008) mention an increase in mortality of 8.4% in Barcelona, Spain, occurring at the same time as an increase in the $PM_{10-2.5}$ concentration values of 10 $\mu g\ m^{-3}$. Middleton et al. (2008) noted a 10.4% increase in cases of cardiovascular disease in Cyprus during dust storm days. Lastly, on the Island of Trinidad in the Caribbean, Gyan et al. (2005) show an increase in the daily hospital admission rates from 7.8 to 9.25 patients, while assuming climatic variables such as pressure and humidity to be constant. In the same area, Monteil (2008) notes a significant rise in the number of paediatric admissions in the seven days following major dust events.

Table 1
Comparison (West Africa/other regions) of air quality measures (PM_{10} indicators).

Indicator	Value	Study area	Study period	Reference
Average annual PM_{10} concentration [$\mu g\ m^{-3}$]	67	Niamey (Niger)	2003	Ozer (2005)
	245	Gouré (Niger)	1984	Ozer et al. (2005)
	108	Nouakchott (Mauritania)	2000	Ozer et al. (2006b)
	18	Northern Spain	1996–1999	Rodriguez et al. (2001)
	30	Southern Spain	1996–2000	Rodriguez et al. (2001)
	49.8	Spain	June 1999–June2000	Querol et al. (2001)
Average monthly PM_{10} concentration [$\mu g\ m^{-3}$]	344	Nouakchott (Mauritania)	2000	Ozer et al. (2006b)
	20–200	Taiwan	1994–1999	Yang (2002)
	200	Middle East	August 1990–August 1991	Draxler et al. (2001)
	400	Uzbek Republic	May 2000–April 2001	Wiggs et al. (2003)
Number of days year^{-1} where 50 $\mu g\ m^{-3}$ PM_{10} threshold is exceeded	51	Nouakchott (Mauritania)	2000	Ozer et al. (2006b)
	4–7	Northern Spain	1996–1999	Rodriguez et al. (2001)
	10–23	Southern Spain	1996–2000	Querol et al. (2001)
Extreme daily mean PM_{10} concentration [$\mu g\ m^{-3}$]	1942	Nouakchott (Mauritania)	January 2000	Ozer et al. (2006b)
	3000–13735	Mali	April–May 1990	Gillies et al. (1996) McTainsh et al. (1997)
	98	Sardinia	March 1991	Molinaroli et al. (1993)
	57	Spain	1996–2000	Rodriguez et al. (2001)
	119	Spain	June 1999–June2000	Querol et al. (2001)
	121	Southeastern USA	1989–1996	Prospero (1999a)
	149	Miami	1983 (23 years)	Prospero (1999b)
	1000	Beijing	Early 2000	Fang et al. (2003)
	1500	Beijing	Early 2000	Xie et al. (2005)
	1779	Korea	2002	Chung et al. (2003)
	1800	Middle East	August 1990–August 1991	Draxler et al. (2001)

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Taken together, these findings raise many questions, for a variety of reasons. There is apparently a need to find out what is happening in West Africa, where the air pollution levels reach values far higher than elsewhere (Table 1), and especially because the mortality and morbidity rates recorded there are much higher than those observed elsewhere in the world. In spite of the estimated values, several studies show that respiratory infections alone often make up more than 20% of the causes of infant mortality (Morris et al., 2003; Bryce et al., 2005). For the Sahelian populations, the following questions can be raised: What are the recurrent diseases close to the main dust source? Can a high concentration of respiratory infections be observed in West Africa? What are the health consequences for populations exposed to levels of pollution that are higher than those found anywhere else? What are the effects of lasting exposure (several consecutive days) to desert dust? How do the populations manage extreme events? Are there differences in the vulnerability of populations by age? How does distance from the source within the continent and position in relation to the dominant winds influence health effects? How to reduce the effects on the populations?

Several factors may help to explain the scarcity of studies on the effects of dust on human health in general and in West Africa in particular. Firstly, the lack of reliable data and the difficulty of obtaining such data are major problems in West Africa. Data on air quality are scarce and not systematic and those on health are often incomplete and/or of poor quality. Secondly, the lack of interaction between the scientific disciplines is surely a major factor. Early this decade, Prospero (2001) recommended that earth science and atmosphere researchers should work together closely with health scientists to understand how dust affects human health. Almost ten years later and the first steps in that direction are only now being taken. Of the 41 studies listed from 1999 to 2009, 32 have been published since 2005 and 20 were published in 2008–2009 alone. It is planned to carry out further research in other literature databases and print literature to search for relevant papers that may not be indexed in the major literature databases. Anyway, the difficulties explained previously can be overcome and the scientific community must now begin to take an interest in the dust impacts close to the Sahara. Above all, this should happen because of the growing evidence that the three main factors affecting natural mineral dust activities – change in land use through anthropogenic pressures, natural climatic variability, and global warming (Goudie, 2009) – are all now helping to increase dust formation (Ozer et al., 2006a). All evidence now suggests that the effects will be amplified in coming years and that the African population, which is the most vulnerable, will also be the most exposed.

6. Conclusion

This systematic review of the available literature on the relationship between desert dust, air quality and human health has highlighted notable gaps. West Africa is clearly more affected by desert dust than in any other parts of the world, due to its proximity to the main emission source area and its location with regard to the dominant winds. However, it is also a region where very little scientific research has been done on the effects of this natural mineral dust on air quality and where practically such research is absent on human health. Nevertheless, whether looking at the effects on air pollution or impacts on human health, studies elsewhere in the world – close to other dust sources that are less important than the Sahara (e.g. Asia) or far from the Saharan source (e.g. Europe and America) – have revealed alarming findings. It is important then to ask a number of questions about the real risks faced by West Africa's populations. The research required to answer these questions is increasingly urgent and vital, particularly in view of worrying changes to the environment.

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