Impact of dust processes on air quality in Niamey, Niger, and consequences on human health

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Abstract
It is now irrefutable that air pollution caused by large amounts of respiratory particulates (Particulate Matter less than 10 µm in aerodynamic diameter, PM_{10}) has numerous undesired consequences on human health. Although air quality degradation far away from the African continent in the US and in Europe caused by high concentration of African dust is seen as a major health threat although most of these countries are very distant from the Sahara; no estimates of PM_{10} levels near the Saharan dust source are available. Based on horizontal visibility observations which are reduced by the presence of dust in the atmosphere, PM_{10} levels are estimated during 2005 at Niamey-Airport, Niger. It appears that excessive concentrations of particles are very important both in magnitude and frequency as the 24-hour PM_{10} thresholds established by the US EPA National Ambient Air Quality Standards and the EU Limits Values for Air Quality were exceeded 103 and 67 times, respectively. The average yearly concentration is far above air quality standards and estimated to 92 µg m^{-3} for PM_{10}. These very high particulate levels are likely to represent an important public health threat and should be considered as a major environmental risk.
Keywords: Air quality; PM_{10}, dust storms; horizontal visibility; Sahel; Niger

1. Introduction

The Sahara largely contributes to the global injection of mineral dust into the northern hemisphere (Prospero et al., 2002; Washington et al., 2003). Yet it is estimated that the Sahara and its margins inject yearly amounts of dust into the atmosphere varying between 600 and 900 10^6 tons (D'Almeida, 1986; Marticorena et al., 1997; Callot et al., 2000), about half of the yearly global mineral dust production (Ginoux et al., 2004).

Over the last decade, mineral dust has become a major topic in environment studies. The increase of aeolian processes observed in most arid and semi-arid areas of the world over the last decades is thought to be a response to environmental stresses and global climate change (Tegen and Fung, 1995; Rosenfeld et al., 2001; Ozer, 2002).

In addition, there is a growing evidence that air pollution caused by increasing concentration of respirable particulates, that is those smaller than 10 µm (PM_{10}), have many local to global environmental and human-related consequences, most of which are adverse. In addition, wind-borne dust may transport bacteria and fungi (Kellogg et al., 2004; Prospero et al., 2005) and can be contaminated with pesticides (O'Hara et al., 2000) or even radioactive (Papastefanou et al., 2001).

Saharan dust is often transported far away to the sources (Middleton and Goudie, 2001). As a result, air quality deterioration caused by high concentrations of respirable African mineral dust has been reported in various regions far away from the sources, such as the Canary Islands (Viana et al., 2002), Spain (Rodriguez et al., 2001; Salvador et al., 2004), the United Kingdom (Ryall et al., 2002), the Middle East (Alpert and Ganor, 2001), the West Indies (Rajkumar and Chang, 2000) and the south-eastern United States (Prospero, 1999). Such mineral particulate matter air pollution is a serious health threat in various regions of the world because it may promote respiratory infection, cardiovascular disease and other ailments (Bielders et al., 2001; Griffin and Kellogg, 2004; Ozer, 2008). High concentration in mineral PM_{10} are cause of morbidity and mortality. Yet, an augmentation of 7.66% of respiratory diseases (+1.12% per 10 µg m^{-3} increase in PM_{10}) and 4.92% of the total mortality (+0.72 per 10 µg m^{-3} increase in PM_{10}) during Mongolian dust outbreaks in Taipei, Taiwan has been recorded (Chen et al., 2004). As far as the Caribbean island of Trinidad, African dust clouds have been associated with increased pediatric asthma accident and emergency admissions (Gyan et al., 2005). Surprisingly, no measurement of ambient air pollution levels near the Saharan dust sources is available (WHO, 2000; Baldasano et al., 2003).

Based on horizontal visibility measurements reduced by mineral dust in the air, this paper estimates PM_{10} concentration levels at the synoptic station of Niamey-Airport, Niger, during year 2005 by using different relations found in the literature. Comparisons with air quality standards from various sources are realized and discussed.

2. Data

The meteorological horizontal visibility is one of the elements world-widely identifying air mass characteristics. In synoptic stations, horizontal visibility is observed on a hourly basis and defined as the greatest horizontal distance at which a black object of suitable dimensions, located near the ground can be seen and recognized when observed against a background scattering of hydrometeors (rain, snow, fog, mist) or lithometeors (dust processes) (WMO 1992). At the synoptic station of Niamey-Airport, 18 targets (buildings, towers, mosques, etc.) with well measured distance to the point of observation are used to estimate horizontal visibility. The international synoptic surface observation code (SYNOP code, WMO 1996) allowed the identification of four classes of dust-related conditions (see detailed information on dust related conditions used in the literature in Ozer, 2000):

1] dust being raised from the ground at the time of the observation (SYNOP codes 07 and 08) and reducing horizontal visibility to less than five kilometers (blowing dust);

2] dust storms, resulting of turbulent wind systems entraining particles of dust into the air, at various degrees of intensity (SYNOP codes 09 and 30 to 36) reducing horizontal visibility to below one kilometer;

3] dust suspended in the air but not being raised from the ground at the time of observation (SYNOP code 06), remnants of earlier deflation events reducing horizontal visibility to less than five kilometers. Dust deposition is noticed at the time of the observation; and

4] haze (SYNOP code 05, presumably caused by dust) reducing horizontal visibility to less than ten kilometers. In this case, no dust deposition is observed which suggests that the dust particles have been raised from the soil at a considerable distance away.

For this study, only dust processes reducing horizontal visibility to five kilometers and below were taken into account. Horizontal visibility were selected on a three-hourly basis, that is at 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, 21:00, and 24:00 UTC.

3. Methods

3.1. Relation between horizontal visibility and PM_{10}

As far as today, only D'Almeida (1986) carried out an in deep study in West Africa on the relation between horizontal visibility and PM_{10} levels of mineral dust mass concentration. Therefore, this paper will be based on the D'Almeida's (1986) correlation analysis linking observed aerosols turbidity, horizontal visibility and mineral dust mass concentration. This was developed on a turbidity network based on 11 stations set up in the Sahara, in the Sahelian belt and in the surrounding southern area during two years (1981 and 1982). Used visibilities range from 200 meters to 40 kilometers and the obtained relation is ($r^2 = 0.95$):

$$C = 914.06\ VV^{-0.73} + 19.03 \qquad \text{[Eq. 1]}$$

where C is the PM_{10} concentration in $\mu g.m^{-3}$ and VV is the horizontal visibility in km.

Comparative suspended mineral dust concentration data for atmospheric dust processes linked with visibility measurements are very scarce in the literature. Reduced visibility to 1.9 km during a yellow sand storm in Kwangju, Korea, was associated with PM_{10} concentrations of 602 $\mu g\ m^{-3}$. (Kim et al., 2001). For this visibility reduction, D'Almeida's relation estimates a concentration in PM_{10} of 591 $\mu g\ m^{-3}$.

This relationship (Eq. 1) is applied to the visibility data of Niamey-Airport in order to retrieve PM_{10} estimates. Obtained results are presented at the daily and derived yearly scale.

3.2. Air quality regulations

Several guidelines and regulations have been adopted to define air quality levels. The US Environmental Protection Agency (EPA) defines the National Ambient Air Quality Standards (NAAQS), and the EU labels the Limits Values for Air Quality (LVAQ). A compilation of the air quality regulation status around the world shows that no such criteria exists in Africa (Baldasano et al., 2003).

For PM_{10}, the EU-LVAQ is the strictest limit with 50 µg m^{-3} not to be exceeded 35 days per year and 7 days per year from 2010. Other 24-hour standard concentration range from 100 to 150 µg m^{-3} (Baldasano et al., 2003). In the USA, the EPA-NAAQS established that the 150 µg m^{-3} threshold can not be exceeded more that once per year, averaged over 3 years. In addition to these daily limits, the US EPA developed the Air Quality Index (AQI) as a tool to provide people with timely and easy-to-understand information on local air quality and whether it poses a health concern (US EPA, 1999). The AQI scale has been divided in six categories, each corresponding to a different level of health concern. The two first AQI categories (good and moderate, < 155 PM_{10} µg m^{-3}) have likely no impact on health, while the last AQI category (hazardous, > 424 PM_{10} µg m^{-3}) is associated with a serious risk of respiratory symptoms and aggravation of lung disease, such as asthma, for sensitive groups and with respiratory effects likely in general population. In between (PM_{10} ranging from 155 to 424 µg m^{-3}), three other categories consider air quality as unhealthy to very unhealthy, especially for sensitive groups.

Estimated PM_{10} concentrations will be systematically compared with threshold values established by US EPA-NAAQS and EU-LVAQ.

4. Results

4.1. Daily PM_{10} concentrations due to Saharan dust

Figure 1 shows the estimated profiles of mean daily PM_{10} concentrations due to mineral dust processes at Niamey-Airport during 2005. The major number of affected days by low air quality mainly occurred in January to March, with 58% and 73% of the yearly number of days above the 24-hour EU-LVAQ (50 µg m^{-3}) and US EPA-NAAQS PM_{10} regulations (150 µg m^{-3}), respectively. Two days with extremely high density of particulate matter are observed on January 6 and 7 with PM_{10} concentrations of 1217 and 1514 µg m^{-3}, respectively. During these two days, horizontal visibility ranged between 0.3 and 1 km due to dust storm activity.

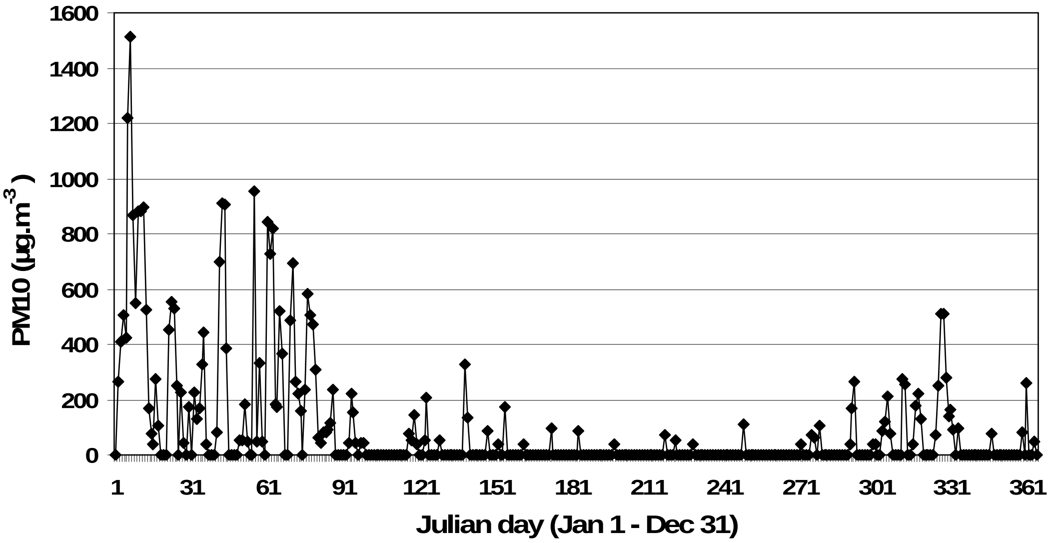

Fig. 1. Estimated daily mean concentrations of PM_{10} (µg m^{-3}) due to Saharan dust events at Niamey in 2005.

Such very high concentrations are not uncommon during very dense dust storms. Chung and colleagues (2003) recorded a 1779 µg m^{-3} concentration in Chongwon-Chongju, Korea. In Beijing, PM_{10} concentrations above 1000 µg m^{-3} were reported during dust storms (Fang et al., 2003). In Kuwait, Draxler and colleagues (2001) measured PM_{10} air concentration exceeding 1800 µg m^{-3} during severe dust storms. In Mauritania, daily PM_{10} concentrations up to 3000 µg m^{-3} were estimated in 2004 during huge dust storms (Ozer, 2008) and PM_{10} concentrations above 1000 µg m^{-3} were also estimated in 2000 (Ozer et al., 2007).

Frequency distribution of estimated daily PM_{10} concentration at Niamey-Airport is shown in Fig. 2. Results suggest that 71.8% of the days were free of mineral dust (<50 µg m^{-3}). Air quality is deteriorated all other 103 days, with 36 days in the 50-150 µg m^{-3} range. Compared with threshold daily PM_{10} concentrations established by the EU-LVAQ, the number of polluted days is about three times above the permitted number of days with

>50 µg m^{-3}, and 15 times higher than the legislation on air quality to enter into force by 2010. For what regards the comparison with the US EPA-NAAQS, 67 days exceed the 150 µg m^{-3} limit value.

Compared with the US EPA-AQI, 24 days (6.6%) may be considered as unhealthy for sensitive groups, 15 days (4.1%) as unhealthy to very unhealthy and 28 other days (7.7%) may be qualified as hazardous. A total of 18.4% of the days was therefore likely to impact human health in Niamey during 2005 because of the high frequency of mineral dust processes.

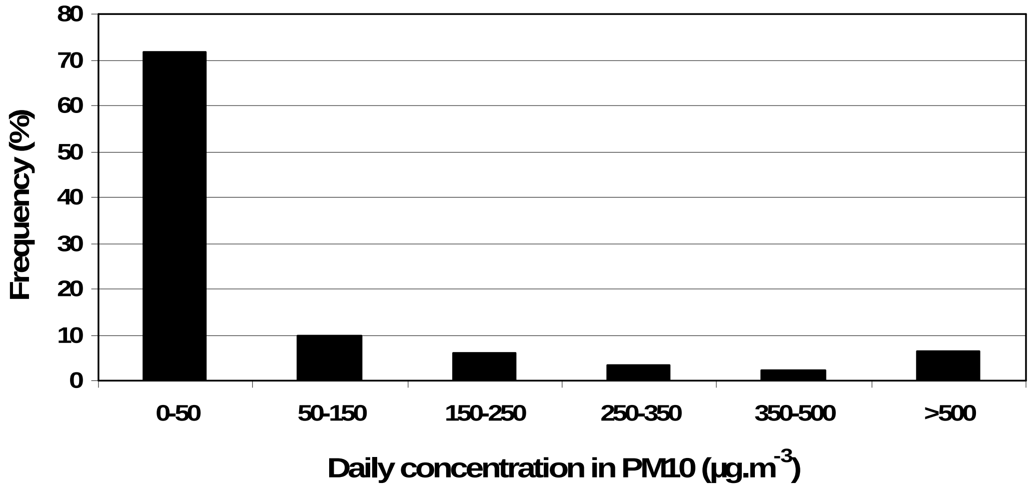

Fig. 2. Distribution of the number of days with selected PM_{10} pollution gradients (µg m^{-3}).

4.2. Yearly PM_{10} values due to Saharan dust

The annual mean PM_{10} concentration presents a value of 92 µg m^{-3} in 2005. This figure is far above the norms adopted in developed countries as it is twice the threshold value established by the US EPA-NAAQS (50 µg m^{-3}) and about five times higher than the limit of the EU-LVAQ yearly mean PM_{10} concentration (20 µg m^{-3}) to enter into force by 2010. Estimated annual mean PM_{10} concentration from visibility impairments in Niamey was of 67 µg m^{-3} in 2003 (Ozer, 2005) and of 108 µg m^{-3} in Nouakchott, Mauritania, in 2000 (Ozer et al., 2007). No comparison can be made with other African data as no measurements nor estimations are available in the recent compilation of air quality data realized by Baldasano et al. (2003). However, according to other annual mean PM_{10} concentration reported by these authors, only the city of Tegucigalpa, Honduras, exceeds the Niamey value with 157 µg m^{-3}. It is worth mentioning here that no records of PM_{10} concentration are available in arid regions from developing countries.

Such values do not estimate the urban air pollution of the city of Niamey where the activities of a rapidly growing urban population (907,000 inhabitants in 2008 against 392,000 in 1988, WWW1) do produce large quantities of particulate matter. This urban air pollution mainly results from increasing traffic of old and badly maintained vehicles on sandy roads, and from individual fires for cooking purposes.

5. Conclusions

The results presented in this study give a estimation of the impact of mineral dust resulting from aeolian processes on air quality degradation in Niamey, Niger, during 2005. A mean annual PM_{10} concentration of 92 µg m^{-3} which dramatically exceeds all various norms established in developed countries is alarming. Daily PM_{10} concentrations exceeded twice 1000 µg m^{-3} in 2005. The EU-LVAQ limit 24-hour PM_{10} concentration (>50 µg m^{-3}) was exceeded 103 days, about 15 times the legislation on air quality to enter into force by 2010. The 150 µg m^{-3} limit value established by the US EPA-NAAQS was exceeded 67 times, with 28 days that may be qualified as hazardous according to the US EPA-AQI.

Developed countries are building up strategies in order to reduce air pollution. On the contrary, most African countries have no air quality regulations, neither the tools to monitor air pollution. It is known that acute respiratory infections among children is one of the major cause of mortality in developing countries, especially in Africa (Black et al., 2003; Ozer, 2008; Romieu et al., 2002; Smith et al., 1999). However, no study of the impact of mineral dust on human health in West Africa was carried out due to the lack of air quality data. Estimations of PM_{10} concentrations derived from horizontal visibility observations could be a first approach to realize such studies.

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